US Army Corps of Engineers

Sacramento District

Sutter Basin Feasibility Study

Butte and Sutter Counties, California

HYDROLOGY APPENDIX

October 2013

SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA
HYDROLOGY APPENDIX

October 2013

Table of Contents

Subject

List of Tables

List of Plates

SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA
HYDROLOGY APPENDIX

JUNE 2012

1. Purpose, Scope, and Authority

1.1 PURPOSE AND NEED FOR THE PROJECT AND REPORT

A high risk of flooding from levee failure threatens the public safety of approximately 80,000 people, as well as property and critical infrastructure throughout the Sutter Basin study area. Past flooding has caused loss of life and extensive economic damages. Recent geotechnical analysis and evaluation of historical performance during past floods indicate the project levees do not meet U.S. Army Corps of Engineers (USACE) levee design standards and are at risk of breach failure at stages less than overtopping. Within the study area, as throughout the Sacramento Valley, floodplain and native habitats have been lost or degraded. Federally listed species and other special status species that are dependent on floodplain habitats have declined. Opportunities exist to restore land formerly converted by mining or agriculture to more natural habitats through Ecosystem Restoration (ER) in conjunction with flood risk management (FRM). There are also opportunities to provide outdoor recreational features on FRM and ER project lands. The purpose of the Sutter Basin Feasibility Study is to address FRM in conjunction with ER and recreation.

The purpose of this hydrology report is to describe the hydrologic features of the basin and to document the design rainfall, the wind-wave analysis, the Sutter Bypass and Feather River discharge frequency, the Cherokee Canal discharge frequency, and the tributary/interior hydrology of the Sutter basin to include the Wadsworth canal discharge-frequency.

1.2 STUDY AUTHORITY

The authority for the U.S. Army Corps of Engineers (USACE) to study FRM and related water resources problems in the Sacramento River Basin, including the study area in Sutter and Butte Counties, is provided in the Flood Control Act of 1962 (Public Law 87-874).

2. Descriptive Information

The study area is located in Sutter and Butte Counties California and is roughly bounded by the Feather River, Sutter Bypass, Wadsworth Canal, Sutter Buttes, and Cherokee Canal. The study area covers approximately 300 square miles and is approximately 43 miles long and 9 miles wide. The study area includes the communities of Yuba City, Live Oak, Gridley, Biggs, and Sutter with a total population of approximately 80,000. Yuba City is the largest community in the study area, with a population of approximately 65,000. A map of the watershed is included as Plate 1 and a map of the study area is included as Plate 2.

The study area is essentially encircled by project levees of the Sacramento River Flood Control Project shown on Plate 3 and high ground of the Sutter Buttes. In 1917, the Federal government authorized the Sacramento River Flood Control Project, which adopted a system of locally built levees as Federal levees, and constructed additional levees, bypasses, overflow weirs, and pumping facilities. Although the Sacramento River Flood Control Project levees were often constructed of poor foundation materials such as river dredge spoils that would not meet today's engineering standards, the levees are relied upon today to provide FRM for numerous communities.

The primary sources of flooding within the study area are the Butte Basin, Sutter Bypass, Feather River, Cherokee Canal, Wadsworth Canal, and local interior drainage. Flood depths and frequency vary throughout the study area. Probability of flooding within the study area is primarily related to the stage of floodwaters within the river channels and the geotechnical probability of levee failure at flood stage.

The Butte Basin is a natural overflow and flood storage area north west of the Sutter Buttes and east of the Sacramento River. The basin provides approximately 1 million acre-feet of transitory storage at flood stage (DWR, 2010). Excess floodwaters from the Sacramento River enter Butte Basin via overbank areas along the river and through the Moulton and Colusa weirs. Butte Creek and its tributaries, including Cherokee Canal, also flow into the Butte Basin. Outflow from the Butte Basin is regulated by hydraulic conditions of Butte Slough and floodplain topography at the upstream entrance to the Sutter Bypass. In order to maintain the flood storage capabilities within Butte Basin, California has included regulation of the overflow area in Title 23 of the California Code of Regulations. In general these standards require approval from the board for any encroachments that could reduce or impede flood flows or would reclaim any of the floodplain within the Butte Basin (DWR, 2010).

The Sutter Bypass is a leveed flood control channel approximately three quarters of a mile wide, bordered on each side by levees. The bypass is an integral feature of the Sacramento River Flood Control Project's flood bypass system. The Sutter Bypass conveys flood waters from the Butte Basin, Sacramento River, and Feather River to the confluence of the Sacramento River and Yolo Bypass at Fremont Weir. Additional flood flows from the Sacramento River enter the Sutter Bypass through Tisdale Bypass. The lower portion of the Sutter Bypass also conveys the Feather River. Within this reach the Feather River is separated from the main conveyance of the bypass by a low levee. This design maintains higher velocities and sediment transport capacity within the Feather River during low flow events while utilizing the large conveyance of the Sutter Bypass during larger events. The Sutter Bypass also receives minor natural flow and agricultural return flow from Reclamation District 1660 to the west and from Wadsworth Canal and DWR pumping plants 1, 2, and 3 to the east. The Sutter Bypass is described by four hydrologic reaches based on tributary inflows; Butte Slough to Wadsworth Canal, Wadsworth Canal to Tisdale Bypass, Tisdale Bypass to Feather River, Feather River to Sacramento River. The Feather River is a major tributary to the Sacramento River, merging with the Sutter Bypass upstream from the Sacramento River and Fremont Weir. The Yuba and Bear Rivers are major tributaries to the Feather River. Two major flood management reservoirs are located within the Feather River watershed: Oroville on the Feather River and New Bullards Bar on the Yuba River. The Feather River is described by four hydrologic reaches based on significant inflows;

Thermalito to Honcut Creek, Honcut Creek to Yuba River, Yuba River to Bear River, and Bear River to Sutter Bypass.

The Cherokee Canal is a tributary to Butte Creek and the Butte Basin. The leveed canal was constructed between 1959 and 1960 by USACE. The canal drainage area is 94 square miles and varies in elevation from 70 feet to 2200 feet. The drainage area is bounded by the Feather River watershed to the east and southeast, Butte Creek and its tributaries to the north and west, and by Wadsworth Canal drainage to the south.

The Wadsworth Canal is a leveed tributary to the Sutter Bypass near the town of Sutter. The canal conveys flow from the East and West interceptor canals to the Sutter Bypass. The East and West interceptor canals collect runoff from canals and shallow floodplain runoff into the Wadsworth Canal.

3. Flood Problems

3.1 GENERAL CHARACTERISTICS

Historically, large areas outside the low-water channel were inundated by Feather River flows in the valley, generally extending from the City of Oroville to the Sacramento River near Verona and encompassing some 292,000 acres, much of which is now agricultural land consisting primarily of orchards, dairy farms, and truck crops. The communities of Marysville and Yuba City are particularly vulnerable to inundation. The average elevation of these two leveed cities varies from 5 to 20 feet below the high water level in the river.

3.2 TOPOGRAPHY

The watershed above Oroville Dam includes mountain crests over 8,000 feet high, mountain valleys at elevations as high as 5,000 feet, deep canyons, and rolling foothills. Elevations range from 10,466 feet at Mt. Lassen Peak to 900 feet at the dam site. A topographic map and stream profiles of the Feather River Basin are presented in Plates 4 and 5.1 and 5.2, respectively. About 58 percent of the basin area is above an elevation of 5,000 feet, and only 7 percent is below 2,500 feet. Table 1 shows the distribution of the basin area above Oroville Dam and the corresponding area-elevation curve is shown on Plate 6. The percentage of the drainage area controlled by the major dams in the Feather River basin and Sacramento River basin downstream to the streamgage at Verona are sown in table 2 below.

TABLE 1

AREA ELEVATION (Percent of Area in Each Elevation)		
ELEVATION RANGE (ft)	AREA (SQMILES)	PERCENT OF AREA
<1000	33	0.9
1000-2000	115	3.2
2000-3000	178	4.9
3000-4000	337	9.4
4000-5000	854	23.7
5000-6000	1,257	34.9
6000-7000	710	19.7
7000-8000	113	3.1
8000-9000	4	0.1
>9000	0.01	0.0
Source: USGS 30 meter DEM		

TABLE 2

Drainage Area and Area Controlled in the Sacramento Basin to Verona						
huc_cd	Station_name	USGS_Stn#	Total Darea(sq-mi)	Local Darea(sq-mi)	Percent of Area Controlled	Elev (ft)
18020005	SACRAMENTO R A KENNETT CA	11369500	6355	6355	100.0%	618
---	Shasta Lake and Dam		6421	6421	100.0%	585
18020101	SACRAMENTO R A KESWICK CA	11370500	6468	47	99.3%	480
18020103	SACRAMENTO R NR RED BLUFF CA	11378000	9020	2599	71.2%	254
18020103	SACRAMENTO R NR HAMILTON CITY CA	11383800	10833	4412	59.3%	
18020103	STONY C NR HAMILTON CITY CA	11388500	773	773	100.0%	150
18020104	SACRAMENTO R A BUTTE CITY CA	11389000	12075	4881	59.6%	
18020104	SACRAMENTO R A COLUSA CA	11389500	12090	4896	59.5%	
18020104	SACRAMENTO R BL WILKINS SLOUGH NR GRIMES CA	11390500	12915	5721	55.7%	
18020104	SACRAMENTO R A KNIGHTS LANDING CA	11391000	14535	7341	49.5%	
18020123	COMPUTED INFLOW TO LK OROVILLE CA	11406799	3607	3607	100.0%	
---	Oroville Lake and Dam		3611	3611	100.0%	180
18020106	FEATHER R A OROVILLE CA	11407000	3624	13	99.6%	
18020106	FEATHER R NR GRIDLEY CA	11407150	3676	65	98.2%	
---	New Bullards Bar Lake and Dam		489	489	100.0%	1392
18020125	N YUBA R BL BULLARDS BAR DAM CA	11413500	487	487	100.0%	1390
18020125	N YUBA R LOW FLOW REL BL NEW BULLARDS BAR DAM CA	11413517	489	2	99.6%	1280
18020125	YUBA R BL NEW COLGATE POWERPLANT NR FRENCH CORRAL	11413700	717	230	67.9%	550
18020125	YUBA R BL ENGLEBRIGHT DAM NR SMARTSVILLE CA	11418000	1108	621	44.0%	
18020125	YUBA R A SMARTSVILLE CA	11419000	1200	713	40.6%	264
18020106	YUBA R A DAQUERRA PT NR BROWNS VALLEY CA	11420800	1330	843	36.6%	
18020107	YUBA R NR MARYSVILLE CA	11421000	1339	852	36.4%	
18020106	FEATHER R BL SHANGHAI BEND NR OLIVEHURST CA	11421700	5334	1236	76.8%	
18020108	BEAR R NR WHEATLAND CA (6.5 mi d/s of Camp Far West Dam)	11424000	292	292	100.0%	72
18020106	FEATHER R NR NICOLAUS	11425000	5921	1531	74.1%	
18020109	SACRAMENTO R A VERONA CA	11425500	21251	10440	50.9%	43

Data Source: USGS gage station inventory at http://nwis.waterdata.usgs.gov/nwis/inventory
Data Source for Dams: Pertinent data sheets for Water Management, Sacramento District, USACE.

3.3 GEOLOGY AND SOILS

Geologically, the Feather River Basin includes portions of the Cascade and Sierra Nevada Ranges. The basin is bounded on the northwest and north by volcanic ridges and mountains radiating from Mt. Lassen, the predominant feature of the northern extremity of the Feather River Basin and the southern limit of the Cascades. On the northeast and east, the basin boundaries correspond roughly to the northern and eastern limits of the Sierra Nevada. The Feather River Basin terminates on the south with the northern boundary of the American River Basin. The majority of the basin is located within the Sierra Nevada, a huge monoclinal fault block tilted very slightly westward and extending beneath the alluvium filled Sacramento Valley on the west. The geologic formations in the basin consist of a wide variety of metamorphic rocks into which granitic rocks of various types have intruded. Recent (in geologic time) stream channel deposits comprise an' important portion of the basin including mountain meadows and stream floodplains, which consist of boulders, gravel, sand and silt. Several faults and fault systems located in areas adjacent to the basin are considered active.

Soils of the Feather River Basin consist of those residual soils formed in place by deterioration and weathering of underlying parent rock; valley fill soils, with the older soils having been modified during the period since deposition and the recent fills showing little change in physical or chemical composition since deposition; and lacustrine soils derived from decomposition of organic materials under marshy conditions. The residual soils are found on mountainous areas and vary in depth from very shallow with considerable surface rock to soils having good depth and little or no surface rock. The older alluvial soils usually have been modified by leaching processes to form dense clay pans or cemented hardpans. These soils are found in lower valley-floor areas, particularly on the west, where they join the alluvial areas of the Sacramento Valley floor. The rich soil of the valley floor below the dam grows a great variety of farm crops.

3.4 SEDIMENT

Sedimentation rates in the Feather River Basin and adjacent basins are relatively low due to limited development, the general shallowness of soils and a low rate of upstream erosion. The annual sediment yield for the drainage area above Lake Oroville is estimated to be about 0.2 acre-feet per square mile, which corresponds to 720 acre-feet/year. Much of the recent deposition that has occurred in the lower Feather River Basin was due to the extensive use of hydraulic mining in the late nineteenth century. DWR conducted a siltation study of Lake Oroville during 1993-1994. The study concluded that 18,000 acre-feet of sediment deposition has occurred since completion of the project. This corresponds to an annual rate of 667 acre-feet/year.

4. Climate

4.1 GENERAL

The climate of the Feather River Basin is significantly influenced by the topography of the area and there are marked variations in temperature and precipitation within short distances. Climate is characterized by cool, wet winters and hot, dry summers. The majority of the annual rainfall occurs in 2 or 3 of the winter months. The seasons are so distinctly different that the period from May to October may be termed the dry season and November to April the wet season.

4.2 TEMPERATURE

Temperatures in the valley are high in the summer and moderate in the winter. Temperatures in the mountains decrease generally with elevation; the summers are moderate at higher elevations while the winters are severe. Observed temperature extremes are113 and 17 degrees at Marysville, 115 and 12 degrees at Oroville, 110 and -24 degrees at Quincy, and 104 and -29 degrees at Sierraville. The monthly and annual distribution of mean, maximum, and minimum temperatures at representative stations are presented in Table 3.Except for extremely high elevations, these temperatures are representative of the whole watershed area.

TABLE 3

MONTHLY AND ANNUAL
MEAN, MAXIMUM, AND MINIMUM TEMPERATURES
(Degrees Fahrenheit)

Month	Marysville (57 ft)			De Sabla (2720 ft)			Canyon Dam (4560 ft)			Portola (4850 ft)		
	Mean	Max	Min	[Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
January	46.0	54.1	38.0	41.7	51.4	31.9	30.5	39.1	21.9	29.9	41.9	17.9
February	51.4	61.1	41.7	43.9	54.4	33.3	33.5	43.4	23.5	33.3	46.1	20.6
March	55.3	66.3	44.3	46.4	57.8	34.9	37.8	49.0	26.6	37.9	51.3	24.4
April	60.8	73.7	47.9	51.4	64.3	38.5	43.8	57.3	30.2	43.2	58.5	27.8
May	67.7	81.8	53.6	58.4	72.6	44.2	51.8	67.3	36.4	50.3	67.5	33.1
June	74.5	90.1	58.9	66.4	82.0	50.9	59.4	76.1	42.7	57.4	76.8	38.1
July	79.1	96.3	61.9	72.3	89.3	55.3	66.0	84.7	47.3	63.6	85.8	41.5
August	77.5	94.5	60.5	71.2	88.5	54.0	64.6	83.5	45.7	62.2	84.4	39.8
September	73.5	89.7	57.3	66.9	83.5	50.4	59.0	76.9	41.2	56.8	78.3	35.3
October	65.3	79.7	50.8	58.4	72.9	44.0	49.5	64.5	34.4	48.4	67.6	29.3
November	53.9	64.7	43.1	47.2	58.1	36.3	38.4	48.5	28.4	38.3	52.5	23.9
December	46.7	55.0	38.4	42.0	51.7	32.3	31.8	39.9	23.6	31.5	43.6	19.5
Annual	62.6	75.6	49.7	55.5	68.9	42.2	47.2	60.9	33.5	46.1	62.9	29.3
Period of Record	1948-2004			1948-2004			1948-2004			1948-2002		

Source: Western Regional Climate Center, 2004

4.3 PRECIPITATION

Annual precipitation varies throughout the drainage area, ranging from 20 to 25 inches on the valley floor to about 100 inches in the higher mountains, and averages about 45 inches over the watershed above Oroville Dam. Winter precipitation usually falls as rain up to the 5,000 foot elevation and as snow at higher elevations, but some storms produce rain up to the highest elevations of the basin and snowfall occurs as low as the valley floor at rare intervals. About 90 percent of the runoff producing precipitation occurs during the winter months of November through April. The areal distribution of normal annual precipitation is shown on Plate 7. The mean monthly distribution at selected stations is given in Table 3.

TABLE 4

MEAN MONTHLY PRECIPITATION								
Month	Marysville (57 ft)		De Sabla (2720 ft)		CanyonDam (4560 ft)		Portola (4850 ft)	
	Inches	%	Inches	%	Inches	%	Inches	%
January	4.37	20.4%	12.75	19.2%	7.4	19.1%	4.13	18.8%
February	3.53	16.4%	10.81	16.3%	6.34	16.4%	3.34	15.2%
March	2.93	13.7%	8.98	13.5%	5.21	13.5%	3.03	13.8%
April	1.61	7.5%	4.93	7.4%	2.6	6.7%	1.34	6.1%
May	0.64	3.0%	2.28	3.4%	1.54	4.0%	1.09	5.0%
June	0.23	1.1%	0.89	1.3%	0.74	1.9%	0.58	2.6%
July	0.04	0.2%	0.1	0.2%	0.18	0.5%	0.36	1.6%
August	0.08	0.4%	0.28	0.4%	0.32	0.8%	0.35	1.6%
September	0.33	1.5%	1.09	1.6%	0.71	1.8%	0.53	2.4%
October	1.27	5.9%	3.65	5.5%	2.2	5.7%	1.18	5.4%
November	2.82	13.1%	8.74	13.2%	4.87	12.6%	2.36	10.7%
December	3.61	16.8%	11.88	17.9%	6.52	16.9%	3.73	16.9%
Average Annual	21.46	100%	66.37	100%	38.65	100%	22.02	100%
Maximum Annual	1983		1983		1983		1996	
Minimum Annual	1976		1976		1976		1976	
Period of Record	1948-2004		1948-2004		1948-200		1919-2004	
Source: Western Regional Climate Center, 2004								

4.4 SNOWFALL

Winter snowfall above 5,000 feet elevation normally accumulates until the first of April when increasing temperatures mark the beginning of the snowmelt season. Snow falling at lower elevations usually melts within a relatively short time. Snow course data are collected at 25 locations within the Feather River Basin by Pacific Gas and Electric Company, California Department of Water Resources, the East Lake Ranger District, and the Eagle Lake Ranger District as part of the California Cooperative Snow Survey program. Basin snowpack data for six representative snow courses are presented in Table 4. The locations of the snow courses are shown on Plate 8.

TABLE 5

SNOW SURVEY DATA (Water Equivalent - Inches)							
Snow Course	AVERAGE					MAXIMUM	MINIMUM
	1-Jan	1-Feb	1-Mar	1-Apr	1-May	(Date)	(Date)
Lower Lassen Peak (Elev 8250 ft.) (POR 1930-2000)	33.4	48.2	62.8	78.7	80.8	162.1 3/27/1995	6.4 1/1/1987
Mount Dyer #1 (Elev 7100 ft) (POR 1930-2000)	9.6	14.5	19.4	25	23	71.7 5/1/1983	0 Multiple
Rowland Creek (Elev 6700 ft) (POR 1950-2000)	6.9	11.8	15.4	17.7	13.3	43.8 4/1/1952	0 Multiple
Eureka Lake (Elev 6200 ft) (POR 1939-2000)	n/a	19.5	28	31.6	21.7	72.9 4/1/1952	0 Multiple
Letterbox (Elev 5600 ft) (POR 1940-2000)	17.8	25.8	37.3	48.4	40.6	106.5 4/1/1952	0 Multiple
Chester Flat (Elev 4600 ft) POR 1930-2000)	3.7	7.5	9	6.4	1.6	29.1 4/1/1952	0 Multiple
Source: California Department of Water Resources, California Data Exchange Center, 2003							

4.5 EVAPORATION AND WIND

The average historical evaporation at Lake Oroville is listed in Table 5. Pan evaporation was measured with a class "A" pan. Peak wind velocities in California are generally associated with winter-type storm fronts, whereas the strongest sustained winds occur in the summer with maximum sunshine. The prevailing wind direction in the lower Feather River Basin is from the south and southeast during the months of April through September, and from the north during the months of October through December. A continuous recording ground level anemometer was recently installed at Oroville Dam. Table 7 is a compilation of the mean and peak monthly wind velocities for Beale Air Force Base and the Red Bluff Airport.

TABLE 6

HISTORICAL MONTHLY PAN EVAPORATION LAKE OROVILLE	
MONTH	MEAN EVAPORATION (in)
January	1.2
February	2.02
March	3.59
April	5.36
May	7.96
June	10.1
July	11.99
August	10.86
September	8.36
October	5.36
November	2.12
December	1.17
Annual Total	70.09

Source: DWR Bulletin 73-79, Nov 1979 (Period of Record WY1959-WY1979). DWR and University of California Statewide Integrated Pest Management Program (Period of Record WY198l-WY2002)

TABLE 7

MEAN AND PEAK MONTHLY WIND VELOCITIES				
Month	Beale Air Force Base		Red Bluff Airport	
	Mean	Peak Gust	Mean	Peak Gust
(mph)	(mph)	(mph)	(mph)	
January	5	59	9	47
February	5	62	9	55
March	6	51	10	60
April	6	53	10	47
May	6	43	9	45
June	6	44	9	41
July	5	38	8	39
August	5	35	8	35
September	5	48	8	43
October	3	53	8	48
November	5	64	8	54
December	5	67	8	49
Annual	5	67	9	60

Source: Climatic Wind Data for the United States, 1998, NCDC, Period of Record not specified.

4.6 STORMS AND FLOODS

The Feather River Basin lies on the seaward face of the Sierra Nevada which rises directly across the path of storms moving inland from the Mid-Pacific Ocean. The low barrier of the Coast Range which intervenes between the ocean and the Sierra Nevada is pierced by the large San Francisco Bay Gap westward from the Feather River Basin so that considerable volumes of moist maritime air reach the basin at low elevations.

The most important storms affecting this area are cyclonic wave disturbances along the polar front that usually originate in the vicinity of the Aleutian Islands. The normal trajectory of the waves along this front is to the south and east from the Pacific Ocean to the west coast. In the summertime, this frontal zone is located far to the north and the accompanying precipitation seldom reaches as far south as California. During the summer the air which reaches the region is generally stable and thunderstorms are rare. During the wintertime, from October to April, the frontal zone moves southward and the cyclonic wave disturbances move over California.

The annual precipitation is concentrated almost entirely during the winter storm season from November through March. Precipitation normally falls as snow above the 5,000 foot level. However, during extremely warm winter storms rain has fallen over the entire basin melting some of the snow and at times stripping most of the snowpack from the basin. By the end of the winter most of the area above 5,000 feet is covered by a compact snowpack that often averages more than 10 feet in depth over large areas. Occasionally, depths reach 30 feet. Because of this deep snowpack in the higher areas, storm rainfall therein is largely absorbed in the mass of the snow and appreciable storm runoff from such areas is prevented.

Studies of storms and floods of record indicate that critical flood producing conditions on the Feather River Basin will occur only during the winter season when there may be a prolonged series of general storms covering the entire basin. Storm precipitation amounts are typically distributed aerially in the same general pattern as normal annual precipitation amounts, although there are large departures from this rule. On occasion a general storm series may last 2 to 5 days. During such stormy periods, soil saturation occurs, infiltration capacities decline, and the natural and artificial storage within the basin is progressively filled.

Outside the winter season, storms are less severe, cover only a small portion of the basin at a time, and are so widely separated in time that basin storages have an opportunity to replenish, resulting in lower basin runoff. Thunderstorms lasting up to three hours can occur over small areas at higher elevations from late spring through early fall. The resulting runoff is characterized by high peaks of short duration with low volumes. For small tributaries, peak flows from thunderstorms can approach those that occur during major winter rain floods, but flows on the main stem are barely affected.

Floods in the Feather River Basin are typical of those occurring on the other Sierra Nevada streams. Floods are rather frequent and of two general types, winter rain floods and spring snowmelt floods. However, only rain floods, resulting from intense rainfall over the foothills and mountains during the winter season, cause serious flooding because the highest rate of snowmelt runoff is well below that corresponding to the damaging stage of the river.

Rain floods have a high peak discharge, are flashy, and are generally only a few days in duration. When antecedent rainfall has resulted in saturated ground conditions or when the ground is frozen, the volume of runoff can be much greater and flooding more severe. These floods may occur in rapid succession with secondary peaks occurring before flows from the preceding floods have completely receded.

Snowmelt floods can be expected any time from April through July. They are characterized by lower peak flows, long durations, and comparably large volumes of runoff. The snowmelt flood potential varies according to the depth and areal extent of the snowpack and temperature. The highest rates of snowmelt runoff usually occur during years with an unusually deep snowpack. High flows are sustained during May and June when rising temperatures cause the snowpack to melt. The top five historic snowmelt inflow flood events are shown in table 9.

4.7 RUNNOFF CHARACTERISTICS

Runoff occurs primarily during the months of November through June. Maximum flows between the months November and April are the result of direct runoff from intense precipitation augmented occasionally by melting snow (USACE, 1958). Runoff during the months of April through June is primarily from snowmelt. Such runoff generally does not result in flood-producing flows, but is ordinarily adequate to fill reservoir space maintained empty during the winter months for flood control. During late summer and early fall, runoff diminishes and streamflow is sustained by springs and drainage of lakes, reservoirs, and areas of effluent seepage (USACE, 1958). Greatest water demands occur during the months June through September. Thus, in years of normal or above normal snowmelt, flood control operation does not interfere with the filling of the reservoir for subsequent water deliveries.

Runoff accumulates rapidly in the upstream tributary areas where the flows are confined within the natural narrow canyon stream channels and the floods produced are of high intensity but relatively short duration. Flood peaks on the streams in the basin above Oroville Dam are often impaired and delayed by numerous upstream check dams, diversions and reservoirs.

Significant runoff occurs after the ground approaches saturation. Thereafter, successive storms would produce runoff with lower loss rates unless enough time expires between storms for the basin to dry out. Loss rates in the basin vary with the wetness of the ground and the intensity of the rainfall plus snowmelt. Constant loss rates, estimated for eight floods between 1940 and 1955, are presented in the March 1958 office report, Flood Control Hydrology, Feather River Basin, California. Constant loss rates were found to range from 0.06 in/hr to 0.13 in/hr.

Annual runoff volume since project completion has been highly variable, and has ranged from a minimum of 752,000 acre-feet in water year 1977 to a maximum of 8,857,000 acre-feet in water year 1983. The extremes represent 18 and 210 percent, respectively, of the 36-year average runoff of 4,227,000 acre-feet. Mean monthly unregulated runoff at Oroville Dam is presented in Table 8.

TABLE 8

MEAN MONTHLY UNREGULATED RUNOFF FEATHER RIVER AT OROVILLE DAM		
MONTH	**TOTAL MONTHLY RUNOFF (1000 AF)**	**PERCENT OF ANNUAL RUNOFF**
JANUARY	509	11.2
FEBRUARY	571	12.6
MARCH	705	15.5
APRIL	739	16.3
MAY	670	14.7
JUNE	349	7.7
JULY	159	3.5
AUGUST	104	2.3
SEPTEMBER	89	2
OCTOBER	106	2.3
NOVEMBER	196	4.3
DECEMBER	350	7.7
ANNUAL	4,547	100.0

The official operation record of Oroville Dam is maintained by the State of California. Operation of Oroville Dam began in October 1967. Daily historical operation data including inflow, outflow, storage and top of conservation are available at the California Data Exchange Center (CDEC) on the web at http://cdec.water.ca.gov/reservoir.html.

4.8 CLIMATE CHANGE

4.8.1. PURPOSE

This section presents a discussion of the potential impact of climate change for the Sutter basin feasibility study (SBFS) hydrology.

4.8. 2. GENERAL

Two possible trends associated with climate change that may affect the SBFS study area are a change in sea level and the shift in Sierra Nevada runoff patterns..

Recent research indicates continued or accelerated rise in global mean sea level height (sea level change) based on decades (and in some cases centuries) of measurements. Climate change has been identified as a likely cause of the increase in global sea level height by many researchers but is still subject to spirited debate. However, the reality of the observed rise in global sea level height at project specific locations and local vertical land movement needs to be adequately addressed by projects in and near coastal areas regardless of the causes (USACE, 2011A).

Also, studies have shown that increasing temperatures associated with climate change are causing a shift in the runoff patterns of Pacific slope watersheds with a large snowmelt component. The runoff shifts for those watersheds include increased runoff in winter, less snowmelt in summer, and earlier runoff in the spring (USACE, 2011B).

4.8.3. SEA LEVEL CHANGE

The discussions of sea-level analysis has been removed to the hydraulic analysis appendix.

4.8.4. IMPACT OF CLIMATE CHANGE ON RUNOFF

A sensitivity study of the potential impact of climate change on runoff was completed. A separate technical memorandum documents that effort in "Sensitivity of Alternative Selection to Climate Change", dated 03January2013 (USACE, 2013).

The procedure used hydrologically was to adopt the percent change in 3-day flood flow at discrete locations in the Sacramento river basin from a paper by Tapas Das (Das, 2011). Those percent changes in 3-day flows were applied to the unregulated flow frequency curves to shift the frequency of future flows to a more frequent occurrence. The future unregulated flows were then input to the economics model were transform curves from the existing without project condition transformed the unregulated flow to regulated flow. The economics model then assessed the ranking of project alternatives based on three future climate scenarios as defined in the Das paper representing wetter and dryer future conditions.

The conclusion of that sensitivity study was that the impact of climate change will not change the selection of draft alternatives for the Sutter Basin Feasibility Study. Table 9 shows the final ranking of alternatives, showing that alternative SB-7 remains in first position. The results indicate that the ranking of the alternatives on the basis of net annual benefits is not sensitive to the climate change scenarios.

TABLE 9.

Rankings of Alternatives Based Upon Equivalent Net Annual Benefits by Climate Scenario

Alternative	NCAR (Driest Condition)	Existing Condition	GFDL (Wettest Condition)
SB-1	8	8	6
SB-2	2	2/3	5
SB-3	4	4	4
SB-4	7	7	8
SB-5	5	5/6	7
SB-6	6	5/6	3
SB-7	1	1	1
SB-8	3	2/3	2

5. Historic Flooding

Historic unregulated flows and volumes for the Feather River at Oroville for the five largest rain floods of record, based on 3-day volumes, are listed in Table 10. Unregulated flows and volumes for the Feather River at Oroville for the five largest snowmelt season (April through July) floods of record based on 3-day volumes are shown in Table 11. A discussion of the 1955, 1964, 1986, and 1997 floods follows.

TABLE 10

HISTORIC RAIN FLOOD INFLOWS
FEATHER RIVER AT OROVILLE DAM

DATE	PEAK a/ (cfs)	UNREGULATED 1-DAY VOLUME (acre-feet)	UNREGULATED 3-DAY VOLUME (acre-feet)
Jan- 1997	302,000	620,600	1,454,800
Feb- 1986	275,000	430,500	1,112,800
Dec- 1964	250,000	354,100	984,100
Mar- 1907	230,000	370,900	894,500
Dec- 1955	203,000	360,100	874,200

Source: USCAE 1999, and CDEC, Period of Record WY 1902- WY 2003 Excerpted fom Oroville DRAFT 2005 WCM a/ Peak flows impaired due to upstream regulation

TABLE 11

HISTORIC UNREGULATED SNOWMELT SEASON INFLOW FLOODS OF RECORD FOR THE FEATHER RIVER AT OROVILLE DAM		
WATER YEAR	1-DAY VOLUME (acre-feet)	3-DAY VOLUME (acre-feet)
1995	491,000	4,263,000
1982	425,000	3,156,000
1915	362,000	2,940,000
1911	308,000	4,368,000
1963	290,000	1,685,000
Source: USACE, CDEC, Period of Record WT 1902 - WY 2003 Excerpted from Oroville DRAFT 2005 WCM Snowmelt season begins April 1st		

During the week preceding Christmas 1955, northern and central California was subjected to one of the greatest floods in the area's history. The intense flood-producing precipitation covered an area of about 100,000 square miles, which represents over sixty percent of the gross area of the state. By December 15, the Feather River Basin was moderately wet from preceding storms, the snowline was at about 4,000 feet, and there was about 36 inches of snow above 7,000 feet. During the first cold phase of the storm, from the 15th to the 20th, about 10 inches of precipitation fell on the basin, as rain below about 5,500 feet and as snow above that elevation. The snowline retreated about 500 feet in elevation, but snow depths at 7,000 feet elevation increased to about 75 inches. After the 21st, temperatures and wind velocities increased greatly and the rainfall extended to the highest point in the basin. The snowline retreated about 700 feet in elevation and snow depths decreased about 18 inches at all elevations, contributing to heavy runoff from most of the basin below above 7,000 feet. Extensive flooding occurred throughout the basin. At Shanghai Bend, south of Yuba City, the west levee of the Feather River failed at about midnight on the 23rd. Water from this break entered Yuba City and flooded about ninety-five percent of the city. In the residential areas, the depth of flooding varied from a few inches to over 12 feet. Because the flooding occurred so quickly, and in the middle of the night, practically none of the contents of homes and businesses could be saved. About 12,000 people were evacuated from the Yuba City area for a period varying from a few days to several months. It was reported that 38 people lost their lives in this area as a result of the flood.

On December 23, 1955, a peak flow of 203,000 cfs and a gage reading of 76.5 feet above streambed occurred at the gaging station in the Feather River Canyon a few miles east of Oroville. An estimated peak discharge of 230,000 cfs occurred during the great flood of March 1907. However, in December 1955, upstream reservoirs, which did not exist in 1907, stored 137,000 acre-feet of floodwater between December 21 and December 28. It is estimated had Oroville Dam existed, the inventoried damages, losses, and costs below the dam site of about $50,000,000 and the loss of human lives could have been prevented. Such a reduction in flood flows in the Feather River would also have relieved the threat to the remaining portion of the levee system.

The flood of December 1964 - January 1965 resulted from a winter rainstorm that followed a meteorological pattern typical of other flood-producing storms over the basin. Heavy precipitation occurred in the preceding 60 days over the general area, with up to 5 inches of rain recorded at some valley stations. The storm came in four distinct waves. The first wave, which occurred during 18-20 December, was cold, and deposited 2-3 inches of snow in the mountains down to the 3,000 foot level. The following wave brought rising temperatures and heavy rains up to 6,000 feet elevation. Within the 4-day period, 20-23 December, about 13 inches of rain fell. The warm winds and rain melted most of the new snow accumulated during the initial storm. Another cold wave occurred during 26 December - 4 January, and brought rain to lower elevations and snow in the mountain. The final wave of this storm series occurred on 4-6 January when 3 to 10 inches of precipitation fell on the Feather and Yuba River Basins. Inflow to Oroville Reservoir peaked at 250,000 cfs. Flow at Oroville was attenuated by the partially constructed dam to a maximum outflow of 158,000 cfs.

The storms of February 1986 severely affected northern California and northwestern Nevada. Heavy precipitation reached record levels in many locations. The heaviest precipitation occurred 200 miles north to 100 miles south of a line from San Francisco to Sacramento to Lake Tahoe. Over much of this area the precipitation ranged between 100 to 350 percent of normal February Precipitation. In the Feather River Basin, the heavy rains began on February 12 and continued through February 21. With the continued rain and storm runoff, storage increases at Oroville from February 13 through February 23 were 640,300 acre-feet or approximately seventy percent of the space available at the beginning of the flood.

Several reservoirs above Oroville contributed to incidental flood flow retention. Collectively, these reservoirs stored 408,000 acre-feet during the flood. The maximum release from Oroville Dam was 147,400 cfs on February 18 and 19. The Feather River at Gridley gage recorded a peak flow of approximately 150,000 cfs on February 19 compared to the past Oroville Dam peak flow of 90,100 cfs on January 15, 1980. Flows on the Feather River below the dam equaled but did not exceed the design flows of the downstream levees. However, on February 20, a levee break occurred on the south bank of the Yuba River at the towns of Linda and Olivehurst causing extensive residential and commercial damage.

Flooding in early January 1997 resulted when a series of three subtropical storms followed a cold storm and one of wettest Decembers on record. Prior to the late December storms, rainfall was already well above normal throughout the Sacramento and San Joaquin River basins. Then, several days before Christmas 1996, a cold storm from the Gulf of Alaska brought snow to low elevations in the Sierra Nevada foothills. The first of three subtropical storms hit Northern California on December 29, 1996, with less than expected precipitation totals. On December 30, the second storm arrived. The third and most severe storm hit late December 31 and lasted through January 2. The snowpack at lower elevations, melted when the trio of warmer storms hit. However, not much snowpack loss was observed at snow sensors over 6,000 feet in elevation in the northern Sierra. Precipitation totals at lower elevations in the Central Valley were not unusually high in contrast to extreme rainfall in the upper watersheds. Extreme precipitation in the Sierra Nevada resulted in record flows in both the Sacramento and San Joaquin River basins. Several gaging stations used to measure the water level in streams and rivers recorded the largest peaks in the history of their operation during this series of storms. Based on 3-day volume, inflows to Lake Oroville were the largest on record. The estimated peak bi-hourly inflow was 302,000 cfs and occurred on 1 January 1997. The maximum release from Lake Oroville was 160,000 cfs. Oroville came close to reaching design capacity as only 27 percent of the flood management reservation pool remained.

The eastern levee of the Feather River failed on the evening of January 3, 1997, near the town of Arboga, California. Within 24 hours of the initial failure, the levee breach had reached over 800 feet in length. Floodwaters inundated 12,000 acres, damaging over 700 structures. Although the area was primarily agricultural, many of the damaged structures were concentrated along Country Club Road and in the town of Arboga. In total, approximately 600 residential structures were within the flooded area. This area had a wide range of flooding depths, with maximum depths about 20 feet (structures totally covered) in the south near the levee break to minimal depths in the north near the Yuba County Airport.

6. Hydrologic Analysis

In support of the Comprehensive Study (USACE, 2002), the Water Management Section of the Sacramento District, USACE, has developed synthetic 50-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedence flood events. These seven synthetic exceedence frequency events will provide a basis for defining existing conditions and eventual alternatives analysis and plan formulation. In this sense, this hydrology study will serve as a cornerstone for future Comprehensive Study investigations.

The methodology used by the Water Management Section of the USACE, in performing the Comprehensive Study, including: 1) updated natural flow frequency curves for locations within the basins; 2) a retrospective of historic floods that have impacted Central Valley rivers and the synthetic flood runoff centerings developed to represent flood events of a specific exceedence frequency; and 3) construction of seven synthetic exceedence frequency flood hydrographs.

The synthetic hydrology, as presented in the Comprehensive Study, was created to be "Comprehensive" in nature. Some watersheds were studied in more detail or had more detailed information available than others; the hydrology presented herein for the Sutter Basin is deemed acceptable for use in a feasibility study. The models developed for the Comprehensive Study analysis were created with the following assumptions and limitations:

- The data are stationary.
- The natural flow frequency curves are strictly rainflood frequency curves. Snowmelt runoff is not directly incorporated into the analysis.
- Centering hydrographs are predicated on flood runoff, not precipitation. The approach was driven entirely by historic flow data; precipitation never entered into any portion of the methodology.
- Storm runoff centerings were formulated based on the Composite Floodplain concept.

- The unregulated frequency curves computed for the Comprehensive Study were created by following procedures outlined in Bulletin 17B.
- Travel times and attenuation factors (Muskingum Coefficients) are fixed for all simulated exceedence frequencies.
- Mainstem unregulated flow frequency curves were designed to quantify the total flows that the basins produced in rainfloods, not the average natural flows expected at mainstem locations during any of the synthetic exceedence frequency storm events.
- Patterns for synthetic floods are formulated based on historic storms.

6.1 STORM CENTERING AND MODELING PROCEDURE

The hydrology for the feasibility study will be based upon the storm centering method described in the Comp Study. A storm centering is the simulation of the effect of storms that are positioned (centered) over particular locations in a watershed to produce flow rates of specific frequencies at those locations. In the Comp Study, a suite of storm centerings were used in developing synthetic hydrology for the Sacramento and San Joaquin watersheds to emulate the diverse spectrum of floods that can occur from different combinations of concurrent storms on tributaries, accounting for orographic influences and other factors that influence regional rainfall runoff events. The synthetic hydrology as presented in the Comp Study represents the best available data for the large flood sources (Sutter Bypass and Feather River) of the Sutter Basin Feasibility Study. The hydrology has also been used for several other feasibility studies in the region, such as the American River Common Features, Yuba River, and Marysville studies.

The synthetic hydrology of the Comp Study was based upon a transformation of unregulated hydrologic conditions to regulated conditions. This was accomplished by developing balanced unregulated hydrographs based upon historical patterned storm events, resulting in hydrographs representing the varying flood durations. These balanced hydrographs were then transformed to regulated hydrographs using an HEC-5 reservoir operations model of the system. The HEC-5 model, also developed and calibrated for the Comp Study, simulates reservoir operations and produces regulated flow (USACE, 1996). Resulting hydrographs were obtained from the HEC-5 model at 'handoff' points and modeled in more hydraulic detail using a UNET unsteady hydraulic model. The Sacramento and San Joaquin Comp Study UNET model, developed and calibrated for the Comp Study, is designed to simulate unsteady flow through a network of open channels, weirs, bypasses, and storage areas (USACE, 2002C).

The Comp Study UNET model downstream of the latitude at the City of Colusa has been replaced for the Sutter Basin Feasibility Study with an HEC-RAS unsteady model. Hydrographs were extracted from the Comp Study UNET model at two locations (a United States Geological Survey (USGS) gage, Sacramento River at Colusa, and a California Department of Water Resources (DWR) gage, Butte Slough at Meridian) and transferred to the HEC-RAS model. The two locations represent the entire flow passing the latitude at the City of Colusa. All model assumptions, flow, and routings upstream from these two locations are from the Comp Study (USACE, 2002). There were several simulations that were done for the Comp Study, however for the Sutter Basin Feasibility Study hydraulic model, the UNET model results from a levee overtopping only and no failure simulation were used.

6.2 DESIGN RAINFALL ANALYSIS

The interior drainage analysis required rainfall depth-duration-frequency tables derived from California Department of Water Resources (DWR) gage data. The data is available on the world-wide-web at: http://www.water.ca.gov/floodmgmt/hafoo/csc/climate_data/ (NOAA, 2011). The Nicolaus and Yuba City gages were selected based on their location , elevation, and period of record. Design storm depths for these gages are provided in Table 12.

TABLE 12

Design Storm Depths [inches].						
	Period of Record	Gage Elevation	100-Year		200-Year	
Rainfall Gage	[year]	[feet]	24-Hr	96-Hr	24-Hr	96-Hr
Nicolaus	91	47	3.38	6.77	3.67	7.4
Yuba City	46	60	3.88	7.33	4.2	8.01
Sutter Buttes [a]	n/a	n/a	4.23	8.46	4.59	9.25

[a] Rainfall depths over the Sutter Buttes were calcuated as 125% of the Nicolaus gage depths.

All subbasins south of Yuba City were assigned storm depths from the Nicolaus gage. The remainder of the subbasins were assigned storm depths according to the Yuba City gage with the exception of the subbasins within the Sutter Buttes. The Sutter Buttes typically receive higher rainfall amounts than the surrounding valley due to orographic effects and were treated as a unique rainfall zone. NOAA atlas 14 point rainfall depths (NOAA, 2011) were evaluated for both the Sutter Buttes and the surrounding valley. From this analysis, it was estimated that the Sutter Buttes typically receive about 25% more rainfall than the surrounding area. Therefore, in the absence of a rainfall gage in the Sutter Buttes, design rainfall depths for this region were estimated as 25% higher than those for the Nicolaus gage.

The 24-hour storm was patterned according to a SCS Type I temporal distribution as recommended in the Sutter County Design Standards (Sutter County, 2005). The 24-hour storm duration was chosen to stress the study area from a peak rainfall intensity and peak flow standpoint.

The 96-hour temporal distribution used was developed for the Sutter Basin region (California- Region 5) as part of the NOAA Atlas 14 Precipitation-Frequency Study for California (NOAA, 2011). The 96-hour storm, although a greater volume, is a less intense storm than the 24-hour storm and was analyzed to stress the study area from a volume standpoint.

The 24-hour and 96-hour temporal distribution patterns are provided in the Sutter Butte Flood Control Agency (SBFCA) Interior Drainage Analysis, dated February 2012, in graphical and table formats.

6.3 WIND WAVE ANALYSIS

The wind wave analysis has been moved to the hydraulic analysis appendix.

7. Analysis for Unregulated Flow Frequency Curves

7.1 GENERAL ANALYSIS

Unregulated frequency curves were developed at key mainstem and tributary locations in both the Sacramento and San Joaquin River basins. Unregulated frequency curves plot historic points and statistical distributions of unimpaired flows (no reservoir influence). Curves display volumes or average flow rates for different time durations over a range of annual exceedence probabilities. These curves can be used to translate: 1) hydrographs to frequencies (i.e., in 1997, the 3-day natural inflow to Oroville Dam, Sacramento River was roughly 209,000-cfs, which translates to a 1.6-percent chance exceedence event); and 2) frequencies to flood volumes (i.e., according to the curves, the 3-day natural inflow to Oroville Dam associated with an annual 10-percent chance exceedence event is approximately 105,000 cfs). After a curve is developed, the runoff volume for any of the seven synthetic exceedence frequency flood events can be obtained from the plot for that curve's specific location.

7.2 UNREGULATED FREQUENCY ANALYSIS

The unregulated frequency curves computed for the Comprehensive Study were created by following procedures outlined in Bulletin 17B, Guidelines for Determining Flood Flow Frequency, U.S. Department of the Interior, dated March of 1982. This report directs Federal agencies to use the procedures included therein for all "planning activities involving water and related land resources." Bulletin 17B requires the use of a Pearson Type III distribution with log transformation of the data (Log Pearson Type III distribution) as the method to analyze flood flow frequency.

In this report, charts containing frequency curves display two types of information. The frequency curve itself is one of these. The curve is derived from a statistical analysis of the recorded data after it has been transformed to log values. The mean, standard deviation and skew of the log-transformed data, are computed for the stream gage or reservoir. The data are screened for high and low outliers and if found, adjustments to the statistics are computed as outlined in Bulletin 17B. In addition, the resulting statistics are reviewed and sometimes adjusted or smoothed to account for sampling error differences among the various durations, or after comparison with similar gages in the watershed or region. The second type of information found on each frequency curve is the plot of the historical events given their estimated frequency. To determine its location on the frequency paper, the peak of each annually recorded event or peak flow value is given a hypothetical frequency based upon its assigned plotting position using a Log Pearson Type III distribution. In some instances, visual examination of the unregulated frequency curves contained in this report reveal a significant difference between the statistical frequency curve and the imaginary curve that would be formed if a pencil line were hand-drawn through the historical data points. For some curves in this report in which the characteristic described above was apparent, further examination was made. In addition, a few frequency curves were re-computed using alternative distributions such as Gumble type III or lognormal. The result was that the other distributions did not result in an improved fit. Bulletin 17B directs the use of a Log Pearson III Distribution unless compelling and substantive evidence can be found that other distributions are more appropriate.

Development of the unregulated frequency curves for the tributaries required daily natural flow data for all target locations. Data were obtained from USACE archives or computed by routing daily change in storage from upstream reservoirs and adding this routed value to the gage record at the location of interest. Most required storage time series were available through USGS publications. Other data were obtained directly from Central Valley and federal water agencies, including U.S. Bureau of Reclamation, U.S. Geological Survey, Oroville-Wyandotte Irrigation District, South Sutter Water District, Placer County Water Association, Nevada Irrigation District, Surface Water Data Inc., Southern California Edison, Sacramento Metropolitan Utility District, and Pacific Gas and Electric.

Data from tributaries were routed to downstream locations for use in constructing mainstem "index" frequency curves. The frequency curves that characterize the total flows through the mainstem index locations represent "at-latitude" flows (i.e., any and all diverted or channelized flows that pass through a particular gage's geographic latitude). Muskingum routings with travel times (in hours) and reach-specific attenuation factors were used to transport daily hydrographs through the basins, as shown in Table 13 for the Sacramento River Basin. Travel times and attenuation factors (Muskingum Coefficients) were obtained from past studies, through communication with local water agencies, or through comparisons of historic flood data. If no information was available from these sources, variables were estimated based on length of reach, average slope, and other channel characteristics. All river routings were assumed to be conservative (routings were simulated with indefinitely large channels); no flow was lost in overbank areas during transit.

TABLE 13

MUSKINGUM ROUTING PARAMETERS FOR SACRAMENTO RIVER BASIN INDEX POINTS				
Source	From	To	Travel Time (Hours)	Muskingum Coefficient
Sacramento River	Shasta Dam	Keswick	2	0.4
Sacramento River	Keswick	Clear Creek	3	0.4
Clear Creek	Whiskeytown Dam	Mouth	2	0.4
Sacramento River	Clear Creek	Cow Creek	2	0.1
Cow Creek	Gage near Millville	Mouth	1	0.2
Battle Creek	Gage below Coleman F.H.	Mouth	1	0.2
Sacramento River	Battle Creek	Bend-Bridge	3	0.1
Sacramento	Bend-Bridge	Ord Ferry	18	0.2
Mill Creek	Gage near Los Molinos	Ord Ferry	14	0.2
Elder Creek	Gage near Paskenta	Ord Ferry	20	0.2
Deer Creek	Gage near Vina	Ord Ferry	14	0.2
Thomes Creek	Gage at Paskenta	Ord Ferry	20	0.2
Big Chico Creek	Gage near Chico	Ord Ferry	6	0.2
Stony Creek	Black Butte	Ord Ferry	11	0.2
Sacramento	Ord Ferry	Moulton Weir	13	0.2
Sacramento	Moulton Weir	Colusa Weir	3	0.2
Sacramento	Colusa Weir	Tisdale Weir	9	0.2
Sacramento	Tisdale Weir	Knights Landing	7	0.2
Sacramento	Knights Landing	Fremont Weir	2	0.2
Ord Ferry Overflow	Ord Ferry	Highway 162	32	0.1
Butte Creek	Gage at Chico	Highway 162	7	0.2
Butte Creek and Ord Ferry Overflow	Highway 162	Moulton Weir	10	0.1
Moulton Weir Spill	Sacramento River	Butte Creek	4	0.1
Butte Basin Flow	Moulton Weir/Butte Creek	Colusa Weir	4	0.1
Butte Basin Flow	Colusa Weir	Butte Sink	16	0.1
Butte Basin Flow	Butte Sink	Tisdale Weir	8	0.1
Sutter Bypass/Tisdale I	Tisdale Weir	Fremont Weir	20	0.1
Feather River	Oroville	Gridley	3	0.2
Feather River	Gridley	Honcut	1	0.17
Feather River	Honcut	Yuba City	4	0.17
North Yuba River	Bullards Bar Dam	Englebright	3	0.15
Yuba River	Deer Creek	Dry Creek	2	0.15
Yuba River	Dry Creek	Marysville	1	0.15
Yuba River	Marysville	Mouth	1	0.15
Feather River	Yuba River	Bear River	8	0.35
Bear River	Wheatland	Mouth	5	0.35
Feather River	Bear River	Nicolaus	2	0.35
Feather River	Nicolaus	Fremont Weir	4	0.2
Sacramento River	Verona	Sacramento Weir	5	0.2

This procedure was not intended to reflect the natural dynamics of the Central Valley, where large flood flows often discharge to out-of-bank areas and are lost or greatly attenuated. The unregulated flow frequency curves were designed to quantify the total flows that the basins produced in rain floods throughout the period of record, rather than the average natural flows expected at mainstem locations during any of the seven synthetic exceedence frequency storm events.

Historical data were plotted using moving averages of the daily time series for 3-, 5-, 7-, 10-, 15-, and 30-day duration natural flow at all points of interest. Wintertime maxima were picked from the moving average for each water year. All snowmelt-driven events were screened out from these duration maxima; screened events were replaced with the highest rainflood, or rainfall driven, maxima experienced during that water year, which included any rain-on-snow events occurring during the obvious rainflood season of a particular annual record. Values were sorted, ranked, and graphed with median plotting positions. Statistics were computed for these samples of annual rainfloods with USACE statistical analysis tools (FFA and REGFREQ). Sample mean, standard deviation, and skew were computed and, in some cases, smoothed to better represent the values for each duration. The Pearson Type III Distribution with log transformation of the data and final statistics were used to construct best-fit curves for all durations and were plotted on the same graph as the historic values for each location.

Unregulated frequency curves were prepared for 43 tributary locations and 8 mainstem locations. In all cases, curves were developed or updated to reflect post-1997 flood hydrology. For any location, the amount of runoff volume produced during simulation of any one of the seven synthetic exceedence frequency flood events can be read off of the family of best-fit curves or computed directly from the final statistical distribution of each duration.

Flood volumes at mainstem index locations represent the sum of volumes contributed by all upstream tributaries, but do not offer any information regarding how each tributary provides to the whole. In this sense, these index curves can provide exceedence frequency targets, in terms of volumes, at mainstem locations for any of the seven synthetic exceedence frequency flood patterns that involve a number of upstream tributaries. During the development process, it was assumed the effects of increased urbanization occurring throughout the period of record were insignificant on the timing of runoff within the watersheds of the Sacramento and San Joaquin rivers. For a further investigation of this assumption, please reference the "Watershed Impact Analysis" done by HEC (USACE, 2002).

The approach formulated and described above was driven entirely by historic flow data. Each year of record included the influence of snowmelt, infiltration, interception, precipitation distribution, timing of runoff, storm development characteristics, and physical basin attributes for that annual rainflood event. Historic flow data records provided a sufficient sample of flood events to characterize hypothetical flood volumes and tributary-system relationships.

No synthetic precipitation events were required. In fact, precipitation never entered into any portion of the methodology.

Design flows and regulated flow-frequency tabular values are shown below in Table 14. The mainstem storm centering for the Sacramento River used for the Sacramento River below Colusa, and the Sutter Bypass is at the latitude of Sacramento. The tributary storm centering for the Feather River below Oroville Dam is centered at Shanghai bend. The frequency curves for the locations of the Sacramento River at Colusa and the Feather River at Shanghai Bend are shown as plates 9 and 10.

TABLE 14. Design Flows and Regulated Flows

Stream & Reach	1957 Authorized Design Flow (CFS)	Regulated Peak Flows (CFS)						
		50% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.5% ACE	0.2% ACE
Sacramento River								
Colusa to Tisdale Weir	66,000	44,000	48,000	50,000	53,000	55,000	59,000	68,000
isdale Weir to Sutter Bypass	30,000	28,000	30,000	31,000	32,000	34,000	36,000	41,000
ther River								
roville to Honcut Creek	210,000	60,000	100,000	150,000	150,000	150,000	174,000	320,400
loncut Creek to Yuba River	210,000	49,000	107,000	157,000	159,600	163,000	182,000	293,600
uba River to Bear River	300,000	71,000	192,000	256,000	281,000	283,000	360,000	534,000
ear River to Sutter Bypass	320,000	78,000	211,000	288,000	321,000	336,000	409,000	574,000
ter Bypass								
leridian to Wadsworth Canal	150,000	57,000	102,000	126,000	155,000	184,000	228,000	327,000
Vadsworth Canal to Tisdale Weir	155,000	58,000	103,000	127,000	156,000	185,000	229,000	327,000
isdale Weir to Feather River	180,000	71,000	117,000	141,000	163,000	197,000	237,000	329,000
eather River to Sacramento River	380,000	141,000	283,000	393,000	436,000	490,000	581,000	799,000
dsworth Canal								
ributary Specific Storm Centering	1,500	820	2,550	3,200	3,980	4,830	5,750	7,070
rokee Canal								
lelson Shipee Road to Western Canal	8,500							
Vestern Canal to Afton Road	11,500	6,000	10,300	12,100	13,200	14,300	15,200	16,300
fton Road to Gridley – Colusa Road	12,500							

Notes: data pulled from PBI Addendum 1 models which are the final models for the Sutter Basin Feasibility Study.
Design flows obtained from USACE drawing file 50-10-3334. Levee Channel Profiles, dated 15 March 1957.
Peak flow is the higher of the Sacramento or Shanghai Bend storm centering peak flows.
Wadsworth Canal and Cherokee Canal peak flows are from unregulated streams.
Peak flows for the 0.5% and 0.2% ACE flood events include effects from levee overtopping and may be reduced from the possible maximums.

7.3 UNREGULATED FREQUENCY CURVES FOR SACRAMENTO RIVER AT THE LATITUDE OF SACRAMENTO AND ORD FERRY

The unregulated frequency curve for the latitude of Sacramento is a tool that can be used to develop a mainstem storm centering. Mainstem centerings were designed to stress widespread valley areas. Index frequency curves were prepared at Ord Ferry and Sacramento in the Sacramento River Basin. These curves provide the hypothetical volumes that the basin will produce during simulations of each of the seven synthetic exceedence frequency flood events. The role of the mainstem centerings is to distribute these volumes back into the basin, tributary by tributary, in accordance with patterns visible in historic flood events. Once the volume is distributed it will be translated into hydrographs and routed through reservoir simulation models (Appendix C of the Comp Study) to produce the synthetic exceedence frequency regulated hydrographs at the two locations needed to construct floodplains throughout the Sacramento river system.

Mainstem centerings reflect a generalized flood pattern based on a number of historic events. Through the incorporation of multiple floods into one characteristic pattern, relationships between tributaries become more stable and the influence of powerful, but isolated, storm cells are downplayed.

The frequency curve for the latitude of Sacramento is shown as plate 11. Flow frequency curves are generated at a specific location, usually a gage location. However, for a river basin a large as the Sacramento River basin, a synthetic storm centering approach is required to correctly portray the discharge probability at locations away from the storm center. Table 15 below shows the percent chance exceedence for selected locations throughout the Sacramento River basin with a storm center at Ord Ferry, while table 16 shows the percent exceedance for a centering at the latitude of Sacramento. A flow-frequency table computed from the statistics shown in the Ord Ferry frequency curve is shown in Table 17 below, while the flows from the centering at the latitude of Sacramento frequency curve is shown in Table 18 below.

TABLE 15 Sacramento River Mainstem at Latitude of Ord Ferry

Synthetic Flood Centerings for Sacramento River Total Flow at Latitude of Ord Ferry							
Index Point	Percent Chance Exceedence						
	50%	10%	4%	2%	1%	0.50%	0.20%
Sacramento River at Shasta	82.08	16.91	5.71	2.41	1.25	0.65	0.28
Clear Creek at Whiskeytown	61.56	15.04	9.03	5.61	2.92	1.52	0.65
Cow Creek nr Millville	61.56	13.53	8.02	3.89	2.02	1.05	0.45
Cottonwood Creek nr Cottonwood	61.56	15.04	9.03	5.61	2.92	1.52	0.65
Battle Creek below Coleman FH	61.56	13.53	8.02	3.89	2.02	1.05	0.45
Mill Creek near Los Molinos	87.94	15.03	7.22	5.94	3.1	1.61	0.69
Elder Creek near Paskenta	87.94	19.33	12.5	10.1	5.26	2.74	1.17
Thomes Creek at Paskenta	87.94	19.33	12.5	10.1	5.26	2.74	1.17
Deer Creek near Vina	87.94	15.03	7.22	5.94	3.01	1.61	0.69
Big Chico Creek near Chico	87.94	15.03	7.22	5.94	3.01	1.61	0.69
Stony Creek at Black Butte	87.94	19.33	12.5	10.1	5.26	2.74	1.17
Butte Creek near Chico	87.94	15.03	10.2	8.42	4.39	2.28	0.97
Feather River at Oroville	87.94	19.33	9.62	8.42	4.39	2.28	0.97
Yuba River at New Bullards Bar	87.94	19.33	11.76	9.18	4.78	2.49	1.06
Yuba River at Englebright	87.94	19.33	11.76	9.18	4.78	2.49	1.06
Deer Creek near Smartsville	87.94	19.33	11.76	9.18	4.78	2.49	1.06
Bear River near Wheatland	87.94	19.33	12.03	10.1	5.26	2.74	1.17
Cache Creek at Clear Lake	87.94	19.33	18.05	12.63	6.58	3.42	1.46
North Fork Cache Creek at Indian Valley	87.94	19.33	18.05	12.63	6.58	3.42	1.46
American River at Folsom	87.94	19.33	14.29	12.63	6.58	3.42	1.46
Putah Creek at Berryessa	87.94	19.33	18.05	12.63	6.58	3.42	1.46

TABLE 16 Sacramento River Mainstem at Latitude of Sacramento

Synthetic Flood Centerings for Sacramento River Total Flow at Latitude of Sacramento							
Index Point	Percent Chance Exceedence						
	50%	10%	4%	2%	1%	0.50%	0.20%
Sacramento River at Shasta	84.42	17.03	8.09	4.41	2.21	1.13	0.44
Clear Creek at Whiskeytown	80.91	17.03	10.79	6.47	3.24	1.66	0.65
Cow Creek nr Millville	80.91	16.18	9.71	5.39	2.70	1.38	0.60
Cottonwood Creek nr Cottonwood	80.91	17.03	10.79	6.47	3.24	1.66	0.65
Battle Creek below Coleman FH	80.91	16.18	9.71	5.39	2.70	1.38	0.60
Mill Creek near Los Molinos	88.26	16.18	9.71	4.22	2.35	1.23	0.51
Elder Creek near Paskenta	88.26	19.42	10.79	4.85	2.70	1.38	0.58
Thomes Creek at Paskenta	88.26	19.42	10.79	4.85	2.70	1.38	0.58
Deer Creek near Vina	88.26	16.18	9.71	4.22	2.35	1.23	0.51
Big Chico Creek near Chico	88.26	16.18	9.71	4.22	2.35	1.23	0.51
Stony Creek at Black Butte	88.26	19.42	10.79	4.85	2.70	1.38	0.58
Butte Creek near Chico	66.70	13.63	6.08	2.75	1.38	0.71	0.30
Feather River at Oroville	53.60	11.78	4.42	2.41	1.20	0.62	0.24
Yuba River at New Bullards Bar	55.09	12.52	4.86	2.10	1.05	0.54	0.21
Yuba River at Englebright	55.09	12.52	4.86	2.10	1.05	0.54	0.21
Deer Creek near Smartsville	55.12	12.52	4.86	2.10	1.05	0.54	0.21
Bear River near Wheatland	53.60	11.13	4.42	2.10	1.05	0.54	0.21
Cache Creek at Clear Lake	52.19	12.52	6.95	4.45	2.22	1.14	0.45
North Fork Cache Creek at Indian Valley	52.19	12.52	6.95	4.45	2.22	1.14	0.45
American River at Folsom	55.09	12.52	4.86	2.51	1.26	0.64	0.25
Putah Creek at Berryessa	52.19	12.52	6.95	4.45	2.22	1.14	0.45

TABLE 17

Unregulated Flow Frequency for the "Ord Ferry" storm centering							
Avg flow[2](cfs) for given duration and AEP[3]							
1/AEP[3]	2	10	25	50	100	200	500
Duration (days[1])	0.5	0.1	0.04	0.02	0.01	0.005	0.002
1	102,000	234,000	317,000	386,000	460,000	541,000	657,000
3	81,000	184,000	247,000	299,000	354,000	414,000	499,000
7	65,000	145,000	193,000	232,000	272,000	315,000	376,000
15	49,000	103,000	131,000	153,000	174,000	196,000	225,000
30	38,000	76,000	97,000	112,000	127,000	143,000	163,000

TABLE 18

Unregulated Flow Frequency for the "at latitude of Sacramento" storm centering							
Avg flow[2](cfs) for given duration and AEP[3]							
1/AEP[3]	**2**	**10**	**25**	**50**	**100**	**200**	**500**
Duration (days[1])	**0.5**	**0.1**	**0.04**	**0.02**	**0.01**	**0.005**	**0.002**
1	157,000	399,000	561,000	700,000	853,000	1,023,000	1,275,000
3	144,000	357,000	498,000	617,000	749,000	894,000	1,108,000
5	132,000	320,000	444,000	547,000	661,000	786,000	969,000
7	122,000	297,000	410,000	506,000	611,000	726,000	894,000
15	97,000	223,000	299,000	361,000	426,000	496,000	595,000
30	76,000	164,000	213,000	252,000	292,000	334,000	390,000

7.4 UNREGULATED FREQUENCY CURVES FOR FEATHER RIVER AT SHANGHAI BEND

7.4.1 Hypothetical Storm Pattern Generation

The intent of this hydrologic analysis is to prepare a hypothetical storm pattern and flood hydrographs that can be fed into reservoir system and hydraulic models for each frequency event (10-, 2-, 1-, and 0.2-percent chance exceedences). In order to define floodplains for this particular reach of the Feather River, synthetic storms centered over this area were developed. The Comprehensive Study includes a number of synthetic storms that produce large floods along the Feather and Yuba rivers, including storms centered at Oroville Dam on the Feather River, Marysville on the Yuba River, and at the Latitude of Sacramento (USACE, 2002). However, none of these storms were centered at locations along the Feather River within this study area. Therefore, hypothetical storms were developed where the most upstream and downstream locations of the study reach (Feather River at Shanghai Bend and the Sacramento River at Latitude of Verona) experience greater intensity than any other location within the Sacramento Valley.

Large floods at Shanghai Bend result from the combination of high flows from both the Yuba River and Upper Feather River. Historically, large events occurring at Shanghai Bend have resulted from rare events occurring on the Upper Feather River (above Oroville) and also on the Yuba River, with one of these rivers having a slightly rarer event than the other. For example, in 1997 a slightly less frequent event occurred at Oroville than on the Yuba River at Marysville, and in 1965 Marysville experienced a less frequent event than Oroville. However, in both of these years, large floods occurred at Shanghai Bend. Because of the possibility that either scenario could happen, two different hypothetical storm patterns were produced. These storm patterns are shown in Tables 19 and 20.

TABLE 19

Feather River Above Shanghai Bend Storm Centering With a Specific Centering on the Yuba River							
Index Point	Percent Chance Exceedence						
	50%	10%	4%	2%	1%	0.50%	0.20%
Sacramento R at Shasta	101.01	20.20	8.08	5.77	2.89	1.44	0.58
Clear Cr at Whiskeytown	344.83	68.97	27.59	19.70	9.85	4.93	1.97
Cow Cr nr Millville	196.08	39.22	15.69	11.20	5.60	2.80	1.12
Cottonwood Cr nr Cottonwood	344.83	68.97	27.59	19.70	9.85	4.93	1.97
Battle Cr blw Coleman FH	196.08	39.22	15.69	11.20	5.60	2.80	1.12
Mill Cr nr Los Molinos	76.34	15.27	6.11	4.36	2.18	1.09	0.44
Elder Cr nr Paskenta	140.85	28.17	11.27	8.05	4.02	2.01	0.80
Thomes Cr at Paskenta	140.85	28.17	11.27	8.05	4.02	2.01	0.80
Deer Cr nr Vina	76.34	15.27	6.11	4.36	2.18	1.09	0.44
Big Chico Cr nr Chico	76.34	15.27	6.11	4.36	2.18	1.09	0.44
Stony Cr at Black Butte	140.85	28.17	11.27	8.05	4.02	2.01	0.80
Butte Cr nr Chico	76.34	15.27	6.11	4.36	2.18	1.09	0.44
Feather R. at Oroville	54.95	10.87	4.35	2.17	1.06	0.53	0.21
Yuba R. at New Bullards Bar	50.00	10.00	4.00	2.00	1.00	0.50	0.20
Yuba R nr Marysville	50.00	10.00	4.00	2.00	1.00	0.50	0.20
Deer Cr nr Smartsville	125.00	25.00	10.00	5.00	2.50	1.25	0.50
Bear R nr Wheatland	125.00	25.00	10.00	5.00	2.50	1.25	0.50
Cache Cr at Clear Lake	153.85	30.77	12.31	6.15	3.08	1.54	0.62
Cache Cr at Indian Valley	153.85	30.77	12.31	6.15	3.08	1.54	0.62
American R at Folsom	76.34	15.27	6.11	3.05	1.53	0.76	0.31
Putah Cr at Berryessa	153.85	30.77	12.31	6.15	3.08	1.54	0.62

Note – The seven frequency storms centered at Shanghai Bend and Verona are the bold values located in the column headers. The concurrent frequency values for each index location are given below each column header. For example, a 2.89% chance exceedence event occurs on the Sacramento River above Shasta Dam during the 1% chance exceedence event centered at Shanghai Bend and Verona.

TABLE 20

Unregulated Flow Frequency for Feather River at Shanghai Bend storm centering							
	Avg flow[2](cfs) for given duration and AEP[3]						
1/AEP[3]	2	10	25	50	100	200	500
Duration (days[1])	0.5	0.1	0.04	0.02	0.01	0.005	0.002
0.0416	93,600	282,800	408,900	513,600	626,300	746,900	918,300
1	73,600	222,600	321,800	404,200	492,900	587,900	722,800
3	56,600	172,200	249,400	313,600	382,800	457,000	562,400
7	39,900	115,800	165,200	205,700	249,000	295,000	359,900
15	29,300	77,600	106,100	128,400	151,200	174,600	206,100
30	22,100	54,900	73,600	88,000	102,600	117,300	137,000

There are only subtle differences between these two storm patterns. These differences lie within the index locations on the Feather and Yuba rivers. For storm centering A, exceedence frequency values generated at Shanghai Bend and the Latitude of Verona are the same as the frequency assigned to the Yuba River. However, for storm centering B, the Yuba River experiences a more frequent event, and the Feather River at Oroville is assigned the same exceedence frequency value that is produced at Shanghai Bend and the Latitude of Verona. In other words, storm centering A has more emphasis on the Yuba River, and storm centering B has more emphasis on the Feather River.

In developing these storm centerings, the guidelines for preparation of mainstem centerings developed for the Comprehensive Study were followed (USACE, 2002). Shanghai Bend and the Latitude of Verona are the bull's eyes of the storm. That is, no other location within the Sacramento River Basin experiences a larger flood than at Shanghai Bend and the Latitude of Verona for the seven hypothetical storms (10-, 2-, 1-, and 0.2- percent chance exceedences). First, the distribution of storm intensity for the Upper Feather and Yuba River basins was developed. Initial exceedence frequency values were assigned to the Yuba River and Feather River index locations. Hydrographs were then constructed at these tributary locations and routed through the system to Shanghai Bend. Duration maxima (peak, 1-, 3-, 7-, 15-, and 30-day) were computed for the hydrographs at Shanghai Bend and compared with the average flows from the frequency curves. The initial pattern was then increased or decreased and the comparison process was repeated until results agreed reasonably with the unregulated rain flood frequency curves.

Once this portion of the pattern was set, the same process was followed for the Latitude of Verona index location. The storm pattern for the rest of the tributary index locations were based upon the average of the Feather and Yuba River storm centerings generated for the Comprehensive Study [#]. This pattern was iteratively adjusted by a fixed percentage until the duration maxima (1-, 3-, 7-, 15-, and 30-day) computed at the Latitude of Verona agreed reasonably with the unregulated rain flood frequency curve at this index location.

The frequency curves used in this process were obtained from the Comprehensive Study (USACE, 2002), except for the Shanghai Bend unregulated flow frequency curve. This curve was adopted from the 1999 FEMA report entitled, "Rain Flood Flow Frequency Analysis, Feather and Yuba Rivers" (USACE, 2002). No adjustments were made to any of the frequency curves except for the peak curve for Shanghai Bend. According to Robert Collins, District Hydrologist, the peak mean for the unregulated flow frequency curve at Shanghai Bend was proportioned based on the relationship of the peak and 1-day means at Oroville, since no peak unregulated data at Shanghai Bend was available. The frequency curve for the Feather River at Shanghai Bend with the modified statistics is presented in Plate 12.

It was determined through a comparison of stages from hydraulic models using as input the hydrology from the various storm centerings that the Feather-Yuba storm centering at Shanghai Bend and the mainstem storm centering at the latitude of Sacramento produced the highest stages. Therefore only those two storm centerings were kept for the analysis of Sutter basin flood risk management.

7.5 UNREGULATED FREQUENCY CURVES FOR CHEROKEE CANAL AT RICHVALE

7.5.1 Purpose:

The hydrology presented in this hydrology appendix for the Butte County portion of the Sutter Basin focuses on the Cherokee Canal, which is a potential source of flooding in the northern portion of the feasibility study area. The hydrology includes the development of flood frequency estimates and 30-day balanced hydrographs for the n-year (50-, 20-, 10-, 4.0-, 2.0-, 1.0-, 0.5-, and 0.2-) percent chance synthetic flood events on the Cherokee Canal from Cottonwood Creek to Afton Road.

7.5.2 Study Area:

The Cherokee Canal, located in Butte County, is tributary to Butte Creek. The Cherokee Canal watershed includes the total drainage above the Cherokee Canal, an artificial channel that flows southwesterly to lower Butte Creek. The watershed is bounded by the Feather River watershed to the east and southeast, by Butte Creek and its tributaries to the north and west, and by Wadsworth Canal drainage to the south. The three primary tributaries to Cherokee Canal are Dry Creek, which, with its tributary, Clear Creek, flows out of the Sierra Nevada foothills, and Cottonwood and Gold Run creeks, which flow west from Table Mountain.

The Cherokee Canal drainage area covers approximately 94 square miles. Its elevation varies from about 70 feet on the Cherokee Canal to about 2,200 feet in the headwaters of Dry Creek. The most heavily urbanized area in the watershed is the incorporated city of Paradise, where the headwaters of Dry and Clear creeks are located. Land use on the valley floor is mostly agricultural, with rice fields predominating. Native vegetation covers the foothills. Plate 14, the general map, shows the boundaries of the upper Cherokee Watershed and the Cherokee Canal watercourse from the headwaters down to the confluence with Butte Creek. Plate 15 shows the area’s topography and a more detailed map of the upper Cherokee Canal drainage.

7.5.3. Background:

Between 1959 and 1960 the Corps of Engineers constructed the Cherokee Canal flood control project from Butte Sink up to Dry Creek. The Federal Flood Control Act of 1944 authorized the construction of the Cherokee Canal as part of several flood control projects on Sacramento River tributaries. The objectives of the Cherokee Canal flood control project were to provide flood protection and to control inflow of sediment into the canal. According to the Cherokee Canal Design Memorandum, dated 15 November 1958, the Cherokee Canal Levee Project included levee construction and channel improvement on the Cherokee Canal and its principal tributaries. The project, as designed, would provide flood protection to 22,000 acres of improved agricultural land, highways, railroads, and irrigation canals. The project begins at the Lower Butte Basin and runs northeasterly to high ground about 13 miles north of Biggs, for a total distance of approximately 22 miles. The design capacity for Cherokee Canal was 8,500 cfs from the upstream end of the canal down to the confluence with Cottonwood Creek, 11,500 cfs from Cottonwood Creek down to Afton Road (the Biggs Princeton Highway), and 12,500 cfs from

Afton Road to the downstream end of the canal. The design capacity reaches are identified on Plate 15.

7.5.4. Stream Gage and Recent Flood History:
A streamflow gaging station was established on the Cherokee Canal at Butte City Road Bridge (State Highway 162). The General Map, Plate 14, shows the location of this streamflow gage, "Cherokee Canal near Richvale," California DWR station A02984. Records for this station have been collected from water year 1961 to present. Flow and stage records are available back to 1976 on the Department of Water Resources Water Data Library website(DWR, 2010). Table 21 lists the five highest flows of record for the Cherokee Canal gaging station. See Section 6.3 for information on the October 1962 high flow event and Section 7.1 for information on other high flow events on the Cherokee Canal.

Table 21

Tabulation of High Peak Flows For Cherokee Canal Gage (DWR Station A02984)	
Peak Flow (cfs)	Date
15,200	13-Oct-62
11,000	13-Jan-69
10,000	11-Mar-89
9,750	21-Jan-64
9,460	24-Dec-83

During the first ten years of the project, several high flows reached or exceeded warning stage at the gage. The high flows deposited sediment from the upstream mining debris in the canal; brush and willows growing in the canal fixed the sediment deposits in place.

On 11 March 1989, a levee break occurred on the left bank of Cherokee Canal just upstream of Nelson-Shippee Road Bridge. The break was caused by overtopping, due to backwater from debris blocking the bridge opening. Design capacity of the canal at this location was 8,500 cfs. Apparently, the levee break resulted from an overnight flood on 11 March that carried enough debris to block the bridge opening and produce a peak flow of 10,000 cfs downstream at the Richvale gage. [#]

During the January 1995 flood, a waterside levee slip occurred on the left levee of Cherokee Canal about 300 feet north of State Highway 162, the location of the "near Richvale" gaging station (Plate 15). The slip was covered with sandbags and plastic to prevent levee failure, which would have flooded several farm houses and the USDA Rice Experimental Station 9USACE, 1995). The observed peak flow at the gage for this event was 8,220 cfs.

The Department of Water Resources removed sediment from various reaches of the Cherokee Canal in 1988, 1989, 1990, and 1996. Occasional high flows down Dry Creek continue to deposit sediment in the Cherokee Canal. Sediment accumulation and vegetation in the canal have reduced its channel capacity such that at some locations the Cherokee Canal channel capacity has been reduced between 37 percent and 44 percent of the original 11,500 cfs design capacity [#].

7.5.5 Hydraulic Analysis – General:

The hydrologic analysis in this appendix uses a hypothetical flood pattern to compute balanced flood hydrographs for an 8-flood synthetic series (50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2% event floods), which will be used in a hydraulic routing model along a critical reach of the Cherokee Canal for a levee break analysis. This critical reach of the canal extends from the Western Canal Levee, at the confluence of Cottonwood Creek, down to the Biggs Extension, about a mile upstream of the Richvale gaging station. The reach is being analyzed to test for a potential left bank levee break that could cause flooding in the town of Biggs to the south. The analysis also includes a test of response time needed to repair a breach in the levee. If the levee is not repaired in a timely manner, later flood waves could increase the flooding to the south. For that reason, the synthetic flood series is 30 days in duration. Hydrographs at the Richvale gaging station are equivalent to those for the critical levee reach as well as for the Cherokee Canal down to Afton Road, the lower end of the hydraulic model. Plate 15 shows the extent of the Cherokee Canal hydraulic model, from Afton Road up to the downstream end of Cottonwood Creek.

7.5.6 Flow Frequency Analysis:

The streamflow gage, Cherokee Canal near Richvale (DWR gage A02984) currently has 46 years of record available, from 1961 to 2006. More recent gaged data are still preliminary. The gage is located at Butte City Road Bridge, 2.1 miles south of Richvale. Flows at the gage are similar to those along the Cherokee Canal reach being analyzed upstream, from the Cottonwood Creek confluence to the Biggs Extension canal. No additional flow enters the canal downstream of the Cottonwood Creek confluence. Daily flows at the gage are available for the period of record; hourly flows are available for water years 1982 to 2006, as well as for the floods of October 1962, January 1964, December 1964, January 1965, and January 1969. DWR Northern District provided a table of annual peak flows for the period of record. Data for the Cherokee Canal near Richvale gage are from (USACE, 2002).

7.5.7 Results and Conclusions:

The unregulated flow frequency of the Cherokee Canal at Richvale is presented in Table 18 below, and on plate 16 at the end of the report. Table 22 lists the peak, and volume flows for the 8-flood series from the flow frequency curves. Plate 17 shows a graphical representation of the 5-day waves for the 8-flood series hydrographs. For this study, it was assumed that the peak flows listed in Table 18 are able to remain in-channel down the Cherokee Canal.

TABLE 22

Peak and Duration Flow Rates for the Synthetic 8-Flood Series Hydrographs							
Percent Exceedence Flood Event	Peak Flow (cfs)	1-Day Flow (cfs)	3-Day Flow (cfs)	5-Day Flow (cfs)	10-Day Flow (cfs)	15-Day Flow (cfs)	30-Day Flow (cfs)
50%	5,900	3,040	1,960	1,540	1,070	869	600
20%	8,700	4,460	2,860	2,260	1,570	1,270	879
10%	10,300	5,280	3,390	2,670	1,860	1,510	1,040
4%	12,100	6,190	3,980	3,130	2,180	1,770	1,220
2%	13,200	6,870	4,360	3,430	2,390	1,940	1,340
1%	14,300	7,310	4,700	3,700	2,580	2,090	1,440
0.50%	15,200	7,780	5,000	3,940	2,750	2,220	1,540
0.20%	16,300	8,340	5,360	4,220	2,950	2,380	1,650

7.5.8. Hydrologic Uncertainty:

EM 1110-2-1619, "Risk-Based Analysis for Flood Damage Reduction Studies," (USACE, 1996), requires use of risk and uncertainty procedures in the evaluation of flood damage reduction studies. An unbroken record of 46 years of stream gage data (1961 to 2006) is available for the DWR station Cherokee Canal near Richvale (DWR gage A02984) that fits a known statistical distribution such as log Pearson III. Based on a review of the flow record and methodology, it is recommended that the systematic record length of 46 years be used as the equivalent record length in the analysis of project performance. The final statistics associated with this record length for the Cherokee Canal near Richvale are:

Mean (Log) = 3.7484
Adopted Standard Deviation = 0.224
Adopted Skew = -0.7

7.6 UNREGULATED FREQUENCY CURVES FOR WADSWORTH CANAL

Wadsworth Canal is an artificial channel that carries rainy season and agricultural runoff from the northeast part of Sutter County south to the Sutter Bypass. The drainage area covers the eastern slopes of the Sutter Buttes, northeastern Sutter County north of the East and West Interceptor canals, and a portion of southern Butte County west of Feather River. The tributaries contributing to Wadsworth Canal are: the West Interceptor Canal and its tributary, Sutter City Lateral; and the East Interceptor Canal with its tributaries (from east to west): Live Oak Slough, RD 777 Lateral 1, Snake River with its tributary, Morrison Slough, and Sand Creek. The drainage area, primarily agricultural, covers about 91 square miles.

The elevation varies from about 54 feet at the upper end of Wadsworth Canal to over 2100 feet on South Butte, the headwaters of the West Interceptor Canal drainage. Aside from Sutter Buttes, the topography of the Wadsworth drainage is relatively flat. The channel capacity of

Wadsworth Canal is 1,500 cfs. During a period of high runoff, the water fills Wadsworth Canal to capacity, then ponds behind the interceptor canals until there is room in Wadsworth Canal to accommodate the ponded water.

The California Department of Water Resources operates two stage gages on Wadsworth Canal:

A0-5927 Wadsworth Canal Near Sutter, Lower Station, and
A0-5929 Wadsworth Canal Near Sutter, Upper Station.

At times, backwater from the Sutter Bypass affects the stage-discharge relationship.

The Wadsworth unregulated frequency curve was developed based on DWR gage A05929, Wadsworth Canal Upper gage. The period of record is 01Oct1939 to 30Sep1996. Annual 1-day maximum flows are available for WY 1939 to WY 1974. Daily data is available from 01Oct1975 to 30Sep1996. The gage was discontinued after WY 1996. A table of peak unregulated flows and volumes for the Wadsworth Canal is shown below in table 23. The flow-frequency curve is shown on plate 18.

TABLE 23

Unregulated Flow at the Wadsworth Canal Upper Gage								
1/AEP	2	5	10	25	50	100	200	500
Duration (days)	0.5	0.2	0.1	0.04	0.02	0.01	0.005	0.002
Peak	817	1,607	2,254	3,197	3,983	4,833	5,750	7,067
1	743	1,390	1,874	2,523	3,024	3,533	4,049	4,740
3	592	1,122	1,522	2,062	2,480	2,906	3,340	3,923
7	455	853	1,151	1,551	1,860	2,173	2,492	2,919
10	400	741	994	1,332	1,591	1,853	2,119	2,474
30	249	434	566	738	867	995	1,124	1,293

7.7 VERIFICATION OF UNREGULATED FLOWS AT INFLOW AND HANDOFF POINTS FOR HYDRAULIC ROUTING

7.7.1. PURPOSE

The purpose of this section is to specify flow hydrographs for use as Sutter Basin Feasibility Study hydraulic model boundary conditions. The Sutter Basin Study Area and hydraulic model hydrologic boundary conditions are illustrated in Plate 19.

7.72. BACKGROUND

A system wide hydrology study of the Sacramento San Joaquin basin was completed in 2002. The study, titled Sacramento San Joaquin Comprehensive Study formed the basis of multiple flood risk management studies throughout the Sacramento and San Joaquin Basins. Several of these studies completed refinements to the hydrologic modeling. Hydrology for the Sutter Basin Feasibility Study is based on the latest hydrologic studies.

7.73. SUTTER BASIN FEASIBILITY STUDY HYDRAULIC MODEL

The Sutter Basin Study Area and HEC-RAS hydraulic model domain are illustrated in the attached Plate 19. The HEC-RAS model is a 1-dimensional unsteady model. The model includes 16 inflow type boundary locations which require hydrograph inputs for 1/2, 1/10, 1/25, 1/50, 1/100, 1/200, and 1/500 AEP flood event simulations.

Due to the size of the tributary area, the hydraulic model is run for two different hydrologic storm-centerings to determine the critical scenario (peak stage and/or flow) at internal model locations. The Sacramento (SAC) storm centering represents a storm centered over the upper Sacramento River watershed with lesser concurrent rainfall/runoff from the Feather/Yuba watershed. The Shanghai Storm Centering (SHY) represents a storm centered over the Feather/Yuba river watershed with lesser concurrent rainfall/runoff from the Sacramento River Basin. Analysis of each storm-centering requires a complete suite of hydrographs (16) for the model boundary conditions. A detailed description of the storm centering procedure is described in the 2002 Comprehensive Study technical documentation (USACE, 2002). The selection of the Sacramento and Shanghai storm centerings from the 25 storm centerings evaluated in the comprehensive study is described in a memorandum for file dated 10 December 2010.

7.74. HYDROGRAPHS

A single DSS file with hydrographs for each of the model boundary locations was provided as a digital attachment as HEC-DSS filename “Sutter_FS_Hydrographs.dss”. Tables are provided in the memorandum to describe the refinements made to the boundary conditions used during plan formulation of conceptual and preliminary alternatives.

A tabulation of the period of record and the peak unregulated flows within the study reaches is shown in table 24. The plates following the references of this report show the frequency curves and notes pertaining to the frequency curve creation.

TABLE 24

Period of Record and Peak Un-Regulated Flows								
Stream and Reach	**Period of Record**	**Un-Regulated Peak Flows (cfs)**						
		1/2	**1/10**	**1/25**	**1/50**	**1/100**	**1/200**	**1/500**
		0.5	**0.1**	**0.04**	**0.02**	**0.01**	**0.005**	**0.002**
Sacramento River								
Colusa to Tisdale Weir	76	111,000	257,000	328,000	406,000	484,000	566,000	681,000
Tisdale Weir to Sutter Bypass	76	169,000	423,000	625,000	756,000	928,000	1,143,000	1,360,000
Feather River								
Oroville to Honcut Creek	94	47,000	136,000	201,000	253,000	311,000	374,000	464,000
Honcut Creek to Yuba River	94	51,000	144,000	211,000	267,000	328,000	394,000	489,000
Yuba River to Bear River	94	84,000	250,000	365,000	459,000	561,000	670,000	827,000
Bear River to Sutter Bypass	94	90,000	265,000	391,000	491,000	599,000	714,000	878,000
Sutter Bypass								
Butte Slough to Wadworth Canal	76	56,700	101,300	126,300	254,800	182,400	225,400	327,400
Wadsworth Canal to Tisdale Weir	76	57,400	103,200	128,900	157,800	186,000	229,400	332,100
Tisdale Weir to Feather River	76	101,200	259,400	342,200	429,100	516,900	607,800	1,215,200
Feather River to Sacramento River	76	169,100	422,600	624,900	755,800	928,200	1,143,400	1,359,700
Wadsworth Canal								
East - West Interceptor to Sutter Bypass								
Concurrent with Sacramento Storm Centering	56	420	1,240	1,300	1,480	1,520	1,550	1,600
Tributary Specific Storm Centering	56	820	2,550	3,200	3,980	4,830	5,750	7,070
Cherokee Canal								
Nelson Shipee Road to Western Canal	-							
Western Canal to Afton Road	46	6,000	10,300	12,100	13,200	14,300	15,200	16,300
Afton Road to Gridley-Colusa Road	-							

Note: Peak un-regulated flows include the effects of headwater reservoir regulation
Note: Peak Un-Regulated flows are the higher of the Sacramento or Shang Shanghai Bend Storm Centerings
Note: The period of record is used in HEC-FDA to establish the confidence limits for the unregulated and regulated flows. The period of record shown above was taken from the unregulated flow-frequency curves that are shown as plates following the references in this report.

8. Reservoir Simulation Model (HEC-5) Routing

The Hydrologic Engineering Center's HEC-5 software (Simulation of Flood Control and Conservation Systems), Version 8.0 (USACE, 1998), was used to route the synthetic tributary flood hydrographs through the reservoir system on the Sacramento River - Basin for analysis of floodplain and channel hydraulics. The Reservoir Simulation Model User's Guide, (USACE, 2003), documents the reservoir model assumptions and methodology for routing the flood hydrographs through two reservoir system models, the headwater reservoirs model, and the lower basin reservoirs model. The reservoir system models routed tributary flows for the entire Sacramento basin; however, the only hydrographs needed for this study are those upstream of and at Hamilton City. The synthetic unregulated hydrographs constructed for Shasta Dam and Valley tributary locations from the Hamilton City flood centering series were input to the reservoir system models to simulate regulated hydrographs at mains tern points on the Sacramento River, including Hamilton City. The Shasta Dam hydrographs were routed through the HEC-5 headwater reservoirs model, to simulate results from regulation by reservoirs upstream of Shasta Dam for the synthetic flood series. The headwater reservoirs are listed on Table 20, and their relative locations shown in the schematic on Plate 20. The simulated regulated inflow hydrographs to Lake Shasta and the downstream tributary hydrographs were then input to the lower basins reservoir model. The schematic on Plate 21 shows the relationship of the reservoirs and the east- and westside tributaries downstream on the Sacramento River.

TABLE 25

LIST OF RESERVOIRS IN THE SACRAMENTO RIVER BASIN ABOVE ORD FERRY						
Reservoir	**Drainage**	**Owner**	**Gross Pool Storage (ac-ft)**	**Drainage Area (sq.mi.)**	**Began Operation**	**Purpose**
Britton (Pit No. 3)	Pit River	Pac Gas & Electric Co	34,600	4700	1925	Water Supply & Hydropower
Pit No.6	Pit River	Pac Gas & Electiic Co	15,700	5020	1905	Water Supply & Hydropower
Pit No. 7	Pit River	Pac Gas & Electric Co	34,000	5170	1965	Water Supply & Hydropower
McCloud	McCloud River	Pac Gas & Electric Co	35,300	380	1965	Hydropower
Shasta	Sacramento, McCloud & Pit.	US Bureau of Reclamation	4,552,000	6665	1945	Flood Management
Whiskeytown	Clear Creek	US Bureau of Reclamation	241,100	201	1963	Water Supply
East Park	Little Stony Creek	US Bureau of Reclamation	51,000	102	1910	Water Supply
Stony Gorge	Stony Creek	US Bureau of Reclamation	50,350	735	1928	Water Supply
Black Butte	Stony Creek	USACE	143,700	741	1963	Flood Management

Modeled Reservoirs in the Feather and Yuba River Basins				
Reservoir	**Tributary**	**Owner**	**Storage Capacity (ac-ft)**	**Drainage Area (sq mi)**
Feather River				
Mountain Meadows	Hamilton Creek	PGE	24,800	158
Almanor	NFk Feather Creek	PGE	1,308,000	503
Butt Valley	Butte Creek	PGE	49,800	86.2
Antelope	Indian Creek	DWR	22,566	71
Bucks Lake	Bucks Creek	PGE	103,000	29.5
Frenchman	Last Chance Creek	DWR	55,477	82
Lake Davis	Big Grizzly Creek	DWR	83,000	44
Little Grass Valley	SFk Feather River	OWID	93,010	27.3
Sly Creek	Lost Creek	OWID	65,050	23.9
Oroville	Feather River	DWR	3,538,000	3,611
Yuba above Marysville				
New Bullards Bar	NFk Yuba River	YCWA	960,000	489
Jackson Meadows	MFk Yuba River	NID	52,500	37.11
Bowman	Canyon Creek	NID	64,000	28.91
Fordyce	Fordyce Creek	PGE	48,900	30
Spaulding	SFk Jackson Creek	PGE	74,773	118
Scotts Flat	Deer Creek	NID	49,000	20
Merle Collins	Dry Creek	BVID	57,000	72.3

TABLE 26

Oroville Release Schedule		
Actual or Forecasted Inflow (Whichever is Greater) (cfs)	Flood Control Space Used (acre-ft)	Required Releases (cfs)
0 – 15,000	0 – 5,000	Power demand
0 – 15,000	Greater than 5,000	Inflow
15,000 – 30,000	0 – 30,000	Lesser of 15,000 or maximum inflow
0 – 30,000	Greater than 30,000	Maximum inflow for flood
30,000 – 120,000	N/A	Lesser of maximum inflow or 60,000
120,000 – 175,000	N/A	Lesser of maximum inflow or 100,000
Greater than 175,000	N/A	Lesser of maximum inflow or 150,000

TABLE 27

New Bullards Bar Release Schedule		
Actual Inflow (cfs)	Flood Control Space Used (ac-ft)	Required Releases (cfs)
0 – 50,000	0 – 170,000	Inflow
50,000 – 120,000	0 – 170,000	Inflow
Greater than 120,000	0 – 170,000	Inflow up to 180,000
Note – Emergency spillway release diagram used when the combination of the rate of rise and pool elevation dictate.		

TABLE 28

Downstream Flow Target Reductions			
Reservoir (cfs)	Downstream Location (cfs)	Target Flow	Reduced Target Flow
Oroville	Yuba City	180,000	174,000
	Below Yuba R. Confluence	300,000	280,000
	Below Bear R. Confluence	320,000	312,000
New Bullards Bar	Marysville	120,000/180,000	106,000/154,000

9. RESERVOIR OPERATIONS MODELING (HEC-ResSim)

Methodology

Reservoir routing for the Feather River system was accomplished using both HEC-5 and the ResSim modeling package produced by the Hydrologic Engineering Center (USACE, 2007). HEC-5 models were constructed for the entire Sacramento River Basin for the Comprehensive Study. A ResSim model for the Feather-Yuba system has been completed by HEC. The spatial extent of this model is shown in Plate 22. ResSim was used to model the Feather River system from Oroville down to Nicolaus. The Comprehensive Study HEC-5 model was used to model the Sacramento River system down to the confluence with the Feather River (Verona). Output hydrographs from both of these models were used as input into the hydraulic models which cover the majority of the main river system (Feather and Sacramento rivers). Hydrograph input locations to the hydraulic model include:

- Feather River below Oroville Dam
- Honcut Creek
- Yuba River at Englebright
- Deer Creek on the Yuba River
- Dry Creek on the Yuba River
- Bear River at Wheatland
- Dry Creek on the Bear River
- Sacramento River at Vina Bridge
- Big Chico Creek
- Stony Creek
- Butte Creek
- Cache Creek
- Putah Creek

The intent of the HEC-5 to ResSim model conversion was to replicate the results of the Comprehensive Study HEC-5 models using ResSim; therefore, all hydrologic routing parameters and methods, starting storage assumptions, and operational rules found in the Comprehensive Study HEC-5 models were incorporated into the ResSim model. All of the reservoirs included in both the headwater and lower basin Comprehensive Study HEC-5 models for the Feather and Yuba River basins are included in this ResSim model (see Table 25 for a complete listing of these reservoirs).

Model Changes

A number of modifications were made to the ResSim model delivered to the Sacramento District by HEC prior to use in the Lower Feather Floodplain Mapping Study. The Comprehensive Study starting storage assumptions for the headwater reservoirs listed in Table 20 were based on the average reservoir storages prior to the December-January 1997, March 1995, and February 1986 flood events. In a floodplain mapping study, storage capability below the normal pool elevation of dams operated primarily for purposes other than flood control should not be considered because the availability of

such storage is uncertain. Therefore, the storages for all but two of the headwater reservoirs were set to gross pool. The storage for both Bucks Lake and Lake Almanor has never exceeded gross pool. Therefore, the maximum storage that has occurred at the lakes for months of December-March was used as the starting storage.
Slight modifications were also made to the ramp-up criteria scripted for Oroville. The Water Control Plan for Oroville specifies a release schedule that is a function of both flood spaced used and actual/forecasted inflow (Table 26).

The original ResSim model developed by HEC did not incorporate the forecasted inflow component of this release schedule. For example, releases would be restricted to 60,000 cfs until an actual inflow exceeded 120,000 cfs. At this time releases would begin to ramp up to the next specified flow value in the schedule (100,000 cfs for this example). In reality, releases would begin to ramp up to 100,000 cfs much earlier than this if a forecasted inflow greater than 120,000 cfs was known. All events greater than the 10% flood have peak flows greater than the largest value in the release schedule (175,000 cfs); so, for these events, Oroville releases were modeled to allow releases to ramp up freely to the maximum objective flow of 150,000 cfs at a rate of 5,000 cfs per hour. This situation is better understood by reviewing tables 26, 27 and 28 above.

Another change to the ResSim model involved travel times. Total travel time from Oroville Dam down to Yuba City was increased from 8 hours to 16 hours, which is consistent with the published travel times used by the Department of Water Resources and is in better agreement with what has been observed.

Lastly, changes were made to the model to incorporate a forecast uncertainty component to the local flow. The original models assumed complete certainty in local flow contributions downstream of a reservoir. This assumption yields high operational efficiency when operating for downstream flow criteria. In reality, however, local flow contributions could be greater or less than what was forecasted. Because of the possibility that local flows could be more than what is forecasted, reservoir releases are typically less than what the calculated releases would be based on the forecasted information. The magnitude of forecast uncertainty can vary from basin to basin and also from storm to storm. The Corps standard is to incorporate a 20% uncertainty in local flow contributions when operating for downstream flow targets. This uncertainty percentage was modeled in ResSim by reducing all downstream flow targets by 20% of the local flow contributing to that specific location. These modifications are listed in Table 28.

Model runs were also simulated assuming complete certainty in local flow contributions for all frequency events. Results from both scenarios were compared for each flood event. The scenario producing the larger of the two flows was selected for the hydraulic analysis. Generally, the complete certainty scenario was selected for events in which the reservoirs were able to satisfy downstream flow criteria, and the 20% uncertainty scenario was selected for those events in which the downstream flow criteria were exceeded.

RESULTS

Discussion of results will focus on the area in which the synthetic storms are centered, the Feather-Yuba system, even though the spatial extent of the storms covered the entire Sacramento River Basin.

Yuba River Basin

Seven reservoirs were modeled within the Yuba River Basin. New Bullards Bar, located on the North Fork of the Yuba River, is the only reservoir that has dedicated flood space. New Bullards Bar, which contains 170,000 acre-feet of flood space, operates to flow targets at Marysville. The flow criteria at Marysville is 180,000 cfs except when the Feather River is experiencing high flows. When the flows in the Feather River upstream of the Yuba River confluence are high, the flow target at Marysville is reduced to 120,000 cfs. This adjustment is made to assure that 300,000 cfs is not exceeded at the confluence of the Yuba River with the Feather River. New Bullards Bar is able to maintain its objective flow of 50,000 cfs for all events through the 2-percent chance exceedence event. For events larger than the 2-percent chance exceedence event, New Bullards Bar outflow exceeds 50,000 cfs. However, the 300,000 cfs flow target at the confluence is still met for the 1-percent chance exceedence event. See Table 29 for a summary of peak flows.

TABLE 29

Effects of Headwater Regulation

Location	Annual Percent Chance Exceedence	Unregulated Peak Flow (cfs)	Regulated Peak Flow (cfs)	% Peak Reduction Due to Regulation
MF + SF of Yuba	10%	38,800	34,100	12.2
	2%	76,400	68,500	10.3
	1%	96,200	87,300	9.3
	0.2%	149,200	137,000	8.2
Deer Creek	10%	4,900	4,600	5.9
	2%	8,700	8,200	5.9
	1%	10,100	9,500	5.9
	0.2%	13,000	12,400	4.9
Dry Creek	10%	4,900	4,600	5.9
	2%	8,700	8,200	5.9
	1%	10,100	9,500	5.9
	0.2%	13,000	11,600	10.9
Oroville Inflow	10%	153,700	135,900	11.6
	2%	284,100	253,100	10.9
	1%	349,600	311,500	10.9
	0.2%	520,300	464,600	10.7

Notes:
% Peak Reduced = ((Maximum Unregulated Inflow)-(Maximum Regulated Inflow))/(Maximum Unregulated Inflow) X 100%
Values are from model simulations of the Feather River Storm Centering A

TABLE 30

Regulated Peak Flows by Hydrologic Routing					
% Chance Exceedance	Feather R. at Oroville	North Yuba R. at New Bullards Bar Dam	Yuba R. at Marysville	Feather R. at Shanghai Bend	Feather R. At Nicolaus
10	100,000	44,400	92,400	200,000	219,000
2	150,000	50,000	150,000	293,000	323,000
1	150,000	66,100	155,000	296,000	323,000
0.2	327,000	150,000	313,000	607,000	668,000

Note - Values at downstream locations are a result of Muskingum hydrologic routing which assumes infinite channel capacity and neglects backwater effects and channel geometry. Hydraulic model output will differ from these results.

The other six reservoirs modeled in the Yuba Basin, known as headwater reservoirs, are much smaller and do not have any dedicated flood space. Even though the model simulations began with the majority of the reservoirs at gross pool, effects of peak attenuation for many locations along the Yuba River was still evident due to surcharge effects (Table 27). Average peak flows along the Middle and South forks of the Yuba River were attenuated by 8.8% for the 1-, 0.5-, and 0.2-percent chance exceedence events.

Feather River Basin

A total of 9 headwater reservoirs were modeled in the watershed above Oroville. Only 20% of the natural flow hydrograph at Oroville was routed through these headwater reservoirs. However, these reservoirs still had a significant impact on attenuating flows into Oroville (Table 27). Average peak inflows to Oroville were reduced by 10.8% for the 1-, 0.5-, and 0.2-percent chance exceedence events.

Oroville Reservoir has a maximum flood space reservation of 750,000 acre-feet, and is required to maintain flow targets at multiple downstream locations. It is also required to maintain flows at or below 180,000 cfs above the Yuba River confluence, 300,000 cfs below the Yuba River confluence, and 320,000 cfs below the Bear River confluence. These criteria were met for all events except the 0.5% chance exceedence event. In these two events releases specified by the Emergency Spillway Release Diagram (ESRD) were triggered. See Table 28 for a summary of peak flow results.

10.0 BEAR RIVER MODEL

10.1 Purpose of Study

The hydrologic analysis described in this section is for the Bear River (a tributary to the Feather River in Northern California). The hydrology developed in this report will be used to support the Sutter Basin feasibility study on the Bear River mainstem and its lower tributaries including Yankee Slough, UP Intercept Canal, and Dry Creek.

10.2 Scope of Study

This study covers the unincorporated areas of Sutter and Yuba Counties, California within the Bear River Watershed. A detailed map of the study area is shown on Plate 26. Products derived include the 10-, 2.0-, 1.0-, and 0.2-percent chance exceedence flood hydrographs for the Bear River at Wheatland, Yankee Slough at Swetzer Road, UP intercept canal at Plumas Lake and Dry Creek at the Best Slough split and Jasper Lane. The above index points coincide with the upstream end of the levees on each stream. Determining interior runoff behind the levees was not within the scope of this hydrologic analysis.

10.3 Basin Description and Reservoir Regulation

The Bear River Basin is located on the western slope of the Sierra Nevada Mountains. The basin is bounded on the north by the Yuba River Basin and has its confluence with the Feather River about 15 miles south of Marysville. The Bear River drains approximately 550 square miles of mountain, foothill, and valley areas. Elevation varies from 6,000 feet to 60 feet above sea level. A topographic map is shown on Plate 27.

Vegetation at the uppermost elevations, where high mean annual rainfall occurs, is covered with dense forest. Much of the Bear River watershed above Wheatland consists of rolling hills vegetated by grass and oak trees. Grazing is the main use for this land. The Dry Creek watershed consists mainly of rolling hills used for grazing or pasture. Beale Air Force Base, located in the middle of the Dry Creek watershed, is urbanized but only constitutes a small percentage of the total land use. The UP Intercept watershed consists of a mix of pasture, irrigated cropland (including rice farming), and urban areas. The main land-use in the Yankee Slough watershed is irrigated cropland.

There are three major reservoirs on the Bear River. New Camp Far West, constructed in 1963, is the most downstream reservoir, has a drainage area of 283 square miles, and is located in the low foothills. The dam is operated by South Sutter Water District for power, irrigation, and recreation. It has a 300 foot long ungated spillway and storage capacity is 104,000 acre-feet. The next reservoir is located 18 miles upstream at Lake Combie. This reservoir is relatively small and only has about 5,000 acre-feet of storage capacity. Rollins Reservoir is the uppermost major reservoir in the watershed, was completed in 1965, and drains the uppermost 104 square miles of the watershed. It has a 300 foot long ungated spillway and a storage capacity of 66,000 acre-feet. This dam is operated by the Nevada Irrigation District. All three reservoirs are operated to fill and spill as early in the rain season as possible; therefore, the only flood control provided is for early season storms that occur while the reservoirs are filling and surcharge storage during spillway flow. The Comprehensive Study in 2001 modeled the Bear River watershed with an HEC-5 Reservoir Model that included Camp Far West and Rollins Dams. Lake Combie was not modeled since storage capacity is minimal. The Comprehensive Study HEC-5 model of the watershed indicates that the reservoirs attenuate the natural peak flow at Bear River at Wheatland by about 11% during the 1% chance exceedence event. This attenuation is due to reservoir surcharge during uncontrolled spillway flow.

10.4 Principal Flood Problems

General rainstorms cause flooding on the mainstem of the Bear River and the larger local tributaries. Due to the relatively low elevation of most of the watershed, snowmelt runoff in the spring does not cause flooding. Localized cloudburst storms would only cause high flows on the smaller drainage basins such as the Linda-Olivehurst area and Yankee Slough. Some melting of the snowpack does occur during general rainstorms such as the January 1997 flood event.

10.5 Flood Protection Measures

Levees have been built along Bear River, Yankee Slough, Dry Creek, Best Slough and the UP Intercept Canal. Except for one reach on upper Yankee Slough (right bank), these levees are part of the Sacramento Flood Control Project. They are maintained by local reclamation districts. The three major upstream reservoirs on the Bear River only provide incidental storage that helps to attenuate the peak of major flood events or store floodwater early in the season before the reservoirs have filled.

10.6 Study Results of Hydrologic Analysis

Peak flood discharges for the 10-, 2.0-, 1.0-, and 0.2-percent chance exceedence events were obtained by using a HEC-HMS (USACE, 2010) rainfall-runoff model that was developed for the Bear River Basin and its tributaries. The subbasin delineation for this model is shown on Plate 31. Table 32 lists peak flows when storms are centered over the specific areas above the outlet point.

TABLE 31

TABLE 1: SUMMARY OF PEAK DISCHARGES					
FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. mi)	PEAK DISCHARGE (CFS EXCEEDENCE FREQUENCY			
		10%	2.0%	1.0%	0.2%
Bear River	292				
At Wheatland		25500	39400	44300	54700
Dry Creek					
Above Best Slough Split	82	9510	13700	15600	19800
At Jasper Lane	101	7470	10900	12500	15900
Best Slough					
Below Dry Creek Split	NA	3330	4810	5460	6920
UP Intercept Canal					
At Plumas Lake	87.2	2780	5060	6290	9630
Olivehurst Canal					
At Plumas Lake	9.46	706	1040	1190	1550
Yankee Slough					
At Swetzer Road	28.4	926	1950	2480	4050

TABLE 32

TABLE 2: SUMMARY OF COINCIDENT PEAK DISCHARGES					
FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. mi)	PEAK DISCHARGE (CFS EXCEEDENCE FREQUENCY			
		10%	2.0%	1.0%	0.2%
Bear River					
At Wheatland	292	25500	39400	44300	54700
Dry Creek					
Above Best Slough Split	82	6990	10500	12000	15500
At Jasper Lane	101	5850	8850	10200	13200
Best Slough					
Below Dry Creek Split	NA	2450	3670	4220	5440
UP Intercept Canal					
At Plumas Lake	87.2	2640	4890	6090	9390
Olivehurst Canal					
At Plumas Lake	9.46	594	900	1040	1360
Yankee Slough					
At Swetzer Road	28.4	761	1720	2220	3760

In addition to computing storm centerings at the above locations, coincident discharges for local tributaries during a centering on the mainstem of the Bear River were computed. Table 30 lists coincident peak discharges at tributary index points when the Bear River at Wheatland gage is experiencing a specific frequency event. Coincident peaks are to be used when specific centerings on the Bear River mainstem are being evaluated.

The Comprehensive Study (USACE, 2002) calculated 1- through 30-day duration frequency curves for the Bear River at Wheatland. The curves were adopted for this study. A peak flow frequency curve was also created for this analysis. Unregulated peak flow values for the Wheatland gage exist for 1929 to 1963, while unregulated flows for the 1- through 30-day durations as calculated by the Comprehensive Study exist for 1929 to 1998. This data was input into HEC's Regional Frequency Computation Program (USACE, 1992). The program derives peak flow statistics based on correlation with the other durations. The 1-day skew was adopted for the peak curve. The adopted peak flow curve along with the other durations derived by the Comprehensive Study are shown in Plate 29. Table 33 displays the unregulated peak flow frequency values adopted for this study.

TABLE 33

Table 8: **Unregulated** Bear River at Wheatland

Peak Flow in CFS	Percent Chance Exceedence
61100	0.2
54700	0.5
49600	1.0
44000	2.0
36100	5.0
29700	10.0

10.7 Coincident Flow on the Feather River

The Bear River hydrologic study conducted as part of the Lower Feather River FPMS computed design hydrographs assuming storms were centering on each tributary as shown in table 29. Then a second set of hydrographs were produced that assumed a storm centered on the Bear River at Wheatland, near the centroid of the basin, shown in table 30. The Sacramento – San Joaquin Comprehensive study and this feasibility study are using two storm centerings: one at the Feather River at Shanghai Bend, and the second at the latitude of Sacramento.

Therefore, the Bear River hydrographs from the Lower Feather River FPMS must be adjusted to match the Bear River at Wheatland flows for the Sacramento and Shanghai Bend storm centering used in this feasibility study. Ratios were computed as the Bear River Shanghai Bend or Sacramento centering peak flow divided by the Bear River hydrology study peak flow. These ratios were then applied to the hydrographs at the other locations including: Dry Creek, Best

Slough, UP intercept, and Yankee Slough, in the Bear River basin for which hydrographs were required in the hydraulic flood routings.

Note: the hydrograph for Dry Creek was not available in the Lower Feather FPMS or the Sacramento centering of the Comp Study. Therefore the hydrograph for Dry Creek for the Sacramento centering was derived from the Shanghai Bend centering by ratio of their peak flows.

The peak flows and ratios for the Bear River hydrology coincident storm centering, and the Comp Study Shanghai Bend and latitude of Sacramento centerings are shown in table 34.

TABLE 34

Table of Peak Flows and Ratios of Peak Flows for the Bear River								
AEP	1/2	1/10	1/25	1/50	1/100	1/200	1/500	Notes
Bear River at Wheatland								
Peak Flow	9251	26290	35828	43049	49201	54664	61972	Comp Study SAC centering
Peak Flow	6000	17100	27800	34600	41400	47700	55300	Shanghai-Yuba FPMS
Peak Flow	8500	25500	33500	39400	44300	49000	54700	Bear River Coincident Flow table
Ratio SAC-BR hydro	1.0884	1.0310	1.0695	1.0926	1.1106	1.1156	1.1330	Ratio of Comp Study SAC to Bear River Coincident peak flows
Ratio SHY-BR hydro	0.7059	0.6706	0.8299	0.8782	0.9345	0.9735	1.0110	Ratio of Comp Study SHY to Bear River Coincident peak flows
Ratio SAC - SHY	1.5419	1.5374	1.2888	1.2442	1.1884	1.1460	1.1207	Ratio of Comp Study SAC to SHY peak flows
Dry Creek at Jasper Lane								
	1700	4600	6200	7300	8300	9300	10500	Comp Study SAC centering
	1100	3000	4800	5900	7000	8100	9400	Shanghai-Yuba FPMS
	-	5850	-	8850	10200	-	13200	Bear River Coincident Flow table
Note: the hydrograph for Dry Creek was not available in the Lower Feather FPMS or the Sacramento centering of the Comp Study. Therefore the hydrograph for Dry Creek for the Sacramento centering was derived from the Shanghai Bend centering by ratio of their peak flows.								
Best Slough blw Dry Creek Split								
	1244	2521	3364	4015	4682	5293	6159	Comp Study SAC centering
	810	1640	2610	3230	3940	4620	5500	Shanghai-Yuba FPMS
	1140	2450	3150	3670	4220	4740	5440	Bear River Coincident Flow table
UP Intercept Canal								
	1089	2726	4084	5344	6765	8371	10644	Comp Study SAC centering
	710	1770	3170	4300	5690	7300	9500	Shanghai-Yuba FPMS
	-	2640	-	4890	6090	-	9390	Bear River Coincident Flow table
Yankee Slough								
	268	784	1312	1883	2471	3194	4258	Comp Study SAC centering
	170	510	1020	1510	2080	2790	3800	Shanghai-Yuba FPMS
	-	761	-	1720	2220	-	3760	Bear River Coincident Flow table

11. Interior Drainage Analysis

11.1. Background

The interior drainage analysis was performed by Peterson-Brustad Incorporated (PBI) a consultant to the Sutter Butte Flood Control Agency (SBFCA). The purpose of the SBFCA analysis was to serve as a submittal to FEMA in conformance with 44CFR65.10 requirements, and to support compliance with the State of California Urban Level of Protection criteria. A supplemental hydraulic analysis was also conducted to be used for the design of replacement levee culverts.

The modeling process consisted of using HEC-HMS to analyze 1% and 0.5% annual exceedance probability (AEP) rainfall-runoff and develop hydrographs at key concentration points in the interior of the Sutter basin, and using FLO-2D to analyze flood depths and boundaries.

A FLO-2D model with a 1,000-foot by 1,000-foot grid size was developed by Peterson Brustad, Inc. (PBI) for the U.S. Army Corps of Engineers' (USACE) Sutter Basin Feasibility Study and later modified to add key interior drainage channels and features. Hydrographs from HEC-HMS were input at concentration points into the FLO-2D model, and FLO-2D was used to route the floods, estimate residual floodplains, and estimate residual flood depths. In this instance, "residual" means floodplains which will exist following accreditation of all levees protecting the Sutter Basin, due to rainfall on the interior areas. These residual floodplains could later be modified through local land use changes or drainage improvement projects. The FLO-2D model and interior floodplain mapping will be discussed in the Hydraulics appendix.

The large grid size is expected to reveal areas of significant SFHA flooding, however, it should be noted that smaller areas of shallow flooding may be missed.

The design storm rainfall analysis was discussed above in section 6.2

11.1.2. Location

The study area includes approximately 340 square miles of Sutter and Butte Counties in Northern California. It is primarily bounded by the Feather River to the east and by the Sutter Bypass and Sutter Buttes in the west. Its southern boundary is at the confluence of the Feather River and the Sutter Bypass. The study area includes the cities of Live Oak, Gridley, Biggs, Yuba City, and the town of Sutter. Plate 30 shows the study area and its main features.

11.2. HEC-HMS MODELING

11.2.1. Model Development

11.2.1. Subbasin Delineation

The first step in developing the HEC-HMS model involved the delineation of drainage shed boundaries. Plate 30 provides an overview of the drainage sheds identified for this study. A total of 16 main sheds covering approximately 340 square miles were identified within the interior drainage study boundary. The main sheds were further divided into a total of 77 subbasins as described below.

Live Oak Slough

The Live Oak Slough watershed includes 2 subsheds covering 16 square miles and drains to the Sutter Bypass through Wadsworth Canal. Subsheds were delineated based on drainage boundaries identified in the City of Live Oak Master Drainage Study (Live Oak, 2011), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Morrison Slough

The Morrison Slough watershed includes 2 subsheds covering 15 square miles and drains to the Sutter Bypass through Wadsworth Canal. Subsheds were delineated based on drainage boundaries identified in the City of Live Oak Master Drainage Study (Live Oak, 2011), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011). RD-777 The RD-777 watershed includes 3 subsheds covering 11 square miles and drains to the Sutter Bypass through Wadsworth Canal. Subsheds were delineated based on drainage boundaries identified in the City of Live Oak Master Drainage Study (Live Oak, 2011), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Snake River

The Snake River watershed includes 10 subsheds covering 32 square miles and drains to the Sutter Bypass through Wadsworth Canal. Subsheds were delineated based on drainage boundaries identified in the Sutter County General Plan (Sutter County, 2010), USGS DEMs (USGS, 2001), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Sutter

The Sutter watershed includes 3 subsheds covering 16 square miles and drains to the Sutter Bypass through DWR Pump Station #3. Subsheds were delineated based on drainage boundaries identified in the Sutter County General Plan (Sutter County, 2010), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Little Blue Creek

The Little Blue Creek watershed includes 2 subsheds covering 6 square miles and drains to the Sutter Bypass through DWR Pump Station #2 (O'Banion Pump Station). Subsheds were delineated based on drainage boundaries identified in the Sutter County General Plan (Sutter

County, 2010), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Lower Snake River

The Lower Snake River watershed includes 4 subsheds covering 20 square miles and drains to the Sutter Bypass through DWR Pump Station #2 (O'Banion Pump Station). Subsheds were delineated based on drainage boundaries identified in the Sutter County General Plan (Sutter County,2010), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

West Interceptor Canal

One subshed covering 8 square miles flows from the Sutter Buttes directly into the West Interceptor Canal which drains to the Sutter Bypass through Wadsworth Canal. Subsheds were delineated based on USGS DEMs (USGS, 2001), (DWR LiDAR data is not available over the Sutter Buttes) and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Sand Creek

The Sand Creek watershed includes 2 subsheds covering 9 square miles and drains to the Sutter Bypass through Wadsworth Canal. Subsheds were delineated based on USGS DEMs (USGS, 2001), DWR LiDAR data (DWR, 2011) and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Sutter City Canal

The Sutter City Canal watershed includes 2 subsheds covering 4 square miles and drains to the Sutter Bypass through Wadsworth Canal. Subsheds were delineated based on USGS DEMs (USGS, 2001), DWR LiDAR data (DWR, 2011) and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Live Oak Canal

The Live Oak Canal watershed includes 3 subsheds covering 15 square miles and drains to the Sutter Bypass through DWR Pump Station #2 (O'Banion Pump Station). Subsheds were delineated based on drainage boundaries identified in the West Yuba City Master Drainage Study (Yuba City, 2006) and the storm drain system outlined in the Sutter County Master Drainage Study (Sutter County, 1979).

Gilsizer Slough

The Gilsizer Slough watershed includes 9 subsheds covering 46 square miles and drains to the Sutter Bypass through DWR Pump Station #2 (O'Banion Pump Station). Subsheds were delineated based on drainage boundaries identified in the West Yuba City Master Drainage

Study (Yuba City, 2006) and the storm drain system outlined in the Sutter County Master Drainage Study (Sutter County, 1979).

Chandler

The Chandler watershed includes 2 subsheds that cover 16 square miles and drains to the Sutter Bypass through DWR Pump Station #1 (Chandler Pump Station). Subsheds were delineated based on drainage boundaries identified in the Sutter County General Plan (Sutter County, 2010), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

RD-823 (Hamatani Ranch)

The RD-823 watershed includes 2 subsheds covering 8 square miles and drains to the Feather River through a private pump station (Hamatani Ranch Pump Station). Subsheds were delineated based on drainage boundaries identified in the Sutter County General Plan (Sutter County, 2010), DWR LiDAR data (DWR, 2011), and the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

Butte Sink

There are 11 subbasins in the northern portion of the study area that drain west to the Butte Sink. These subbasins total 94 square miles and were delineated based the main drainage channels identified in Sutter County's GIS layer (Sutter County, 2011).

East Biggs

The East Biggs subbasin totals 6.01 square miles. The Butte Canal makes up its western boundary and, based on a phone conversation with the director of the Joint Water Board, this section of the Butte Canal has the ability to capture storm runoff from this area. This subbasin was modeled, but its runoff was not conveyed beyond the Butte Canal boundary.

Feather River

Although most of the interior lands drain in a southwesterly direction away from the Feather River's west levee, there are 19 subsheds covering 25 square miles that drain directly to the Feather River through levee culverts or pump stations. These sheds are independent from the rest of the HEC-HMS model and were delineated to assist SBFCA in the design of replacement levee culverts. Sheds were identified based on DWR LiDAR data (DWR, 2011), the City of Live Oak Master Drainage Study (Live Oak, 2011), the West Yuba City Master Drainage Study (Yuba City, 2006), the Sutter County Master Drainage Study (Sutter County, 1979) and telephone conversations with City of Yuba City officials.

11.3.1.7. Pump Stations and Detention Ponds

Ten stormwater pump stations were included in the analysis (see Plate 30). Three DWR pump stations discharge stormwater to the Sutter Bypass. Capacities for these pump stations were obtained from the DWR Sutter Maintenance Yard (DWR, 2009).

One private pump station (Hamatani Ranch Pump Station) is identified in the Sutter County General Plan (Sutter County, 2010) and discharges to the Feather River. A utilities inventory (Flowserve Inc, 2010) conducted along the Feather River's west levee identified this pump station as a Byron Jackson 17HQH pump. Its pump capacity was obtained from a BJ 17HQH pump curve (Flowserve Inc, 2010).

Six pump stations that drain areas in and around Yuba City and discharge to the Feather River were included in the analysis. Five of these pumps are operated by the City of Yuba City. Capacities for these pumps and their associated detention ponds were estimated by the City of Yuba City. An additional pump station operated by the Gilsizer Drainage District also drains Yuba City. Pump and pond capacities for this pump station were obtained from the Gilsizer Drainage District. Ponds are pumped dry after each storm, so ponds were assumed empty at the start of each simulation.

Pump station data are summarized in Table 35.

Table 35. Pump station capacities.

Pump Station	Details
DWR PS#1	Total Capacity: 280 cfs 4 pumps @ 70 cfs each
DWR PS#2	Total Capacity: 786.6 cfs 6 pumps @ 131.1 cfs each
DWR PS#3	Total Capacity: 182.2 cfs 4 pumps @ 45.55 cfs each
Hamatani Ranch PS	Total Capacity: 9.3 cfs 1 pump @ 9.3 cfs
Yuba City Pump Station #1	Total Capacity: 6,820 gpm (15.2 cfs) 1 pump @ 1,950 gpm; 1 pump @ 770 gpm; 1 pump @ 4,100 gpm Pond Capacity: 9 Acre-Feet (AF)
Yuba City Pump Station #2	Total Capacity: 7,300 gpm (16.3 cfs) 2 pumps @ 3,000 gpm; 1 pump @ 1,300 gpm Pond Capacity: 46 Acre-Feet (AF)
Yuba City Pump Station #3	Total Capacity: 9,800 gpm (21.8 cfs) 3 pumps @ 40 horsepower each Pond Capacity: 68.9 Acre-Feet (AF)
Yuba City Pump Station #4	Total Capacity: 900 gpm (2.0 cfs) Pond Capacity: 15 Acre-Feet (AF)
Yuba City Seepage Pump Station	Total Capacity: 9,700 gpm (21.6 cfs) 1 pump @ 3,270 gpm; 1 pump @ 6,430 gpm Total Capacity: 47,500 gpm (105.8 cfs)
Gilsizer Drainage District Pump Station	2 pumps @ 10,000 gpm; 1 pumps @ 5,000 gpm; 1 pumps @ 22,500 gpm Pond Capacity: 70 Acre-Feet (AF)

[a] Estimated based on horsepower and capacities of similarly sized pumps in Yuba City.

11.3.3. Model Results

Once calibrated, the HEC-HMS model was run with the four design storm events described above in section 6.2. The simulations were extended several days beyond the storm event to ensure that hydrographs had time to return to low-flow conditions and runoff had time to travel to the model's outlet points. Table 36 and Table 37 provide a summary of peak flow and runoff volume results at several key locations in the study area.

In the absence of gage records, high water marks, or other physical tools for model verification, PBI verified results through discussions with several area officials from the City of Yuba City, Sutter County, and Gilsizer Drainage District, as well as with residents within the basin who recalled flooding that took place during the 1997 and 2006 events.

TABLE 36

Location	Drainage Area [sq.mi.]	100yr-24hr	100yr-96hr	200yr-24hr	200yr-96hr
Summary of peak flow results [cfs].					
Live Oak Slough					
at Highway 99	5.97	90	54	110	67
at East Interceptor Canal confluence	18.06	470	120	580	140
RD777 Canal					
at Sheppard Rd	4.66	330	150	410	180
Morrison Slough					
d/s of Sutter/Butte County Line	5.35	290	150	350	190
Snake River					
West Fork at Sutter/Butte County Line	3.87	210	160	250	180
East Fork at Sutter/Butte County Line	2.85	220	170	260	190
u/s of Clark Rd.	29.75	1,900	1,600	2,300	1,900
at Morrison Slough confluence	45.34	2,600	2,300	3,100	2,700
Interceptor Canal					
at RD777 Canal confluence	28.52	1,000	440	1,300	540
at Snake River confluence	74.95	3,700	2,900	4,400	3,400
at Wadsworth Canal entrance	95.44	4,900	4,100	5,900	4,800
Wadsworth Canal Outlet	96.12	4,900	4,200	5,900	4,900
Sutter Main Canal					
DWR Pump Station #3 Inflow	16.26	1,200	520	1,500	650
Little Blue Creek					
at Highway 20	1.43	91	53	110	60
Live Oak Canal					
at Highway 20	4.37	150	100	180	120
at Bogue Rd	10.01	440	220	530	280
Lower Snake River					
at Highway 20	3.08	400	120	480	140
at Little Blue Creek confluence	15.78	780	540	940	630
at Live Oak Canal confluence	31.91	1,600	1,000	2,100	1,200
Gilsizer Slough					
at Lincoln Rd.	6.85	380	380	430	420
at Bogue Rd.	8.36	510	460	560	500
at Oswald Rd.	14.04	700	510	820	560
at George Washington Blvd.	38.28	1,200	690	1,600	810
DWR Pump Station #2 Inflow	87.25	3,100	2,600	3,800	3,000
Chandler Main Drain					
DWR Pump Station #1 Inflow	10.68	540	460	680	520
RD-823 Main Drain					
at Highway 99	3.58	110	21	150	31
Hamatani Ranch Pump Station Inflow	7.63	210	180	270	210
Average Unit Peak Flows [cfs/acre]		0.08	0.05	0.1	0.06

Table 37

Summary of runoff volume results [acre-feet].					
Location	Drainage Area [sq.mi.]	100yr-24hr	100yr-96hr	200yr-24hr	200yr-96hr
Live Oak Slough					
at Highway 99	5.97	340	340	400	410
at East Interceptor Canal confluence	18.06	890	610	1,100	700
RD777 Canal					
at Sheppard Rd	4.66	330	610	390	700
Morrison Slough					
d/s of Sutter/Butte County Line	5.35	330	350	400	460
Snake River					
West Fork at Sutter/Butte County Line	3.87	390	1,100	440	1,200
East Fork at Sutter/Butte County Line	2.85	250	540	290	620
u/s of Clark Rd.	29.75	2,700	6,500	3,100	7,400
at Morrison Slough confluence	45.34	4,200	9,000	4,900	10,000
Interceptor Canal					
at RD777 Canal confluence	28.52	1,700	1,900	2,000	2,200
at Snake River confluence	74.95	6,100	11,000	7,100	13,000
at Wadsworth Canal entrance	95.44	7,800	15,000	9,200	17,000
Wadsworth Canal Outlet	96.12	7,800	15,000	9,200	17,000
Sutter Main Canal					
DWR Pump Station #3 Inflow	16.26	1,200	2,100	1,400	2,400
Little Blue Creek					
at Highway 20	1.43	140	380	150	420
Live Oak Canal					
at Highway 20	4.37	370	470	430	530
at Bogue Rd	10.01	770	930	900	1,100
Lower Snake River					
at Highway 20	3.08	250	520	290	600
at Little Blue Creek confluence	15.78	1,400	3,600	1,600	4,000
at Live Oak Canal confluence	31.91	2,700	5,600	3,100	6,400
Gilsizer Slough					
at Lincoln Rd.	6.85	980	1,700	1,100	1,900
at Bogue Rd.	8.36	1,200	2,100	1,300	2,300
at Oswald Rd.	14.04	1,400	2,300	1,500	2,500
at George Washington Blvd.	38.28	2,100	2,900	2,500	3,200
DWR Pump Station #2 Inflow	87.25	6,500	12,000	7,500	14,000
Chandler Main Drain					
DWR Pump Station #1 Inflow	10.68	940	1,900	1,100	2,100
RD-823 Main Drain					
at Highway 99	3.58	120	160	160	180
Hamatani Ranch Pump Station Inflow	7.63	520	1,300	600	1,400
Average Unit Runoff Volumes [AF/acre]		0.13	0.24	0.15	0.27

12. Analysis of Alternatives by Hydrology

The ring levee and J-levee (the levee) around Yuba City are the two alternatives that required additional hydrologic analysis. The fix-in-place, and other similar levee alternatives will not require a change in the hydrology effecting those alternatives.

For the preliminary screening, an estimate of the runoff within the levee was developed using the rational method of rainfall-runoff analysis. Rainfall depths were extracted from the design rainfall analysis by David Ford Consulting Engineers Inc (Ford) for this study. The Ford analysis is based on rainfall depth-area-duration statistics developed by Jim Goodrich, the former California State Climatologist, and kept up-to-date on the Department of Water Resources (DWR) web site. Areas within the levee were developed from Google Earth sketches of the proposed alternative alignment. The loss rate coefficient was calibrated to match the peak flows shown the West Yuba City master drainage study.

A mean daily flow rate of 918 cfs was estimated for the whole area inside the levee. The area used was 24.23sq.mi. within the levee. A 1-day, 10-year precipitation volume of 2.82 inches, and a rainfall-runoff coefficient of 0.5 was used. Pumps were sized based on this average flow rate. These estimates have been used in the study to this point. Refinements will be made as shown below.

The interior drainage analysis performed by Peterson-Brustad Inc (PBI) for SBFCA using HEC-HMS and FLO2D later determined the 100-year and 200-year 24-hour storm duration flow at two locations. The two locations are natural drainage outlets that must pass through the levee, and include Gilsizer Slough and Live Oak Slough. The discharge and volume at these two locations is shown in tables 33 and 34 to be: 440 and 530 cfs for the 24-hour, 100- and 200-year return periods respectively at Live Oak Slough. And, 1200 and 1600 cfs for the 24-hour, 100- and 200-year return periods respectively at Gilsizer Slough.

The pump size required must be determined in conjunction with an accompanying detention basin. The larger the detention basin, the smaller the required pump size. A detailed analysis of the interior drainage within the ring levee alternatives was done by PBI. In addition, pump sizes and detention basin sizes were calculated. Those results may be found in the Interior Drainage Analysis by Peterson-Brustad, Inc. (SBFCA, 2012).

13. Results

The results of the design rainfall analysis, the discharge probability of the Sutter Bypass and Feather River systems, the Cherokee and Wadsworth Canal systems, and of the Sutter basin interior areas tributary to the Wadsworth canal and the Sutter Bypass are shown above. For further information see the individual reports, Technical Memorandum, and Memorandum for Record.

14. Conclusions

This summary report provides information for the determination of a feasible project within the Sutter Basin, California. This is the complete hydrology appendix document for the Sutter Basin Feasibility Study Draft Report. The information summarized herein is detailed in technical memorandums, and memorandum for record. Those memos are cited in the text above and shown in the references below.

15. REFERENCES:

A number of existing reports and references have been utilized as part of the Pilot Study effort. The following contain the most relevant information for the current Pilot Study hydrology effort.

<u>Technical Memorandum in Direct Support of this Hydrology Summary</u>

Sutter Butte Flood Control Agency (SBFCA), "Interior Drainage Analysis", prepared by Peterson-Brustad, Inc. February 2012.

USACE. "Cherokee Canal Hydrology Appendix, Cottonwood Creek to Afton Road, Butte County, California, Sutter Basin General Investigation Feasibility Study", revised August 2010.

USACE. "Sutter Bypass Storm Centering and Flow Hydrograph Selection Justification For the Sutter Basin Feasibility Study, General Investigations Hydrology Technical Memorandum.", January 2011.

Das T, Dettinger, MD, Cayan, DR, Hidalgo, Hugo G, 2010. Potential increase in floods in California's Sierra Nevada under future climate projections. Springer Science+Business Media B.V. 2011.

<u>California Department of Water Resources</u>

California Department of Water Resources and Jim Goodridge, "Rainfall Depth Duration Frequency (daily amounts) for precipitation stations in Sutter and Yuba counties", http://www.water.ca.gov/floodmgmt/hafoo/csc/climate_data/, Revised 2005.

California Department of Water Resources. November 2010. State Plan of Flood Control Descriptive Document, Central Valley Flood Management Planning Program.

California Department of Water Resources. Accessed June 2011. Rainfall Depth Duration Frequency Data, Available Online at: http://www.water.ca.gov/floodmgmt/hafoo/csc/climate_data/#.

California Department of Water Resources. 2004 Land Use Survey data acquired from DWR, 23 May 2011.

California Department of Water Resources. Rainfall data at SMF gage, obtained from California Data Exchange Center (CDEC) website, 15 May 2011.

California Department of Water Resources. Pump data records, obtained from Sutter Maintenance Yard via U.S. Army Corps of Engineers, 13 May 2011.

Reports from additional Sources

Butte County. August 1998. Butte Creek Watershed Project. Site visited August 2010. <http://buttecreekwatershed.org/Watershed/ECR.htm#Chapter>

California State University, Chico. Butte Creek Watershed Project Existing Conditions Report, Chapter 8, "Historical Uses and Cultural Resources" and Appendix F, Annotated Bibliography.

City of Live Oak, Master Drainage Study, Prepared by West Yost & Associates, March 2011.

City of Yuba City, West Yuba City Master Drainage Study, Prepared by West Yost & Associates, March 2006.

Das T, MD Dettinger, DR Cayan, Hugo G, Hidalgo (2010) Potential increase in floods in California's Sierra Nevada under future climate projections. Springer Science+Business Media B.V. 2011.

David Ford, Consulting Engineers. July 1998. Design-storm Runoff: Sutter County, California. Public Works – Road Department. Sutter County, California.

David Ford, Consulting Engineers. June 2011. Technical Memorandum on Rainfall frequency calculations, Sutter Basin, California.

Dettinger, M.D. (Dettinger, 2005). "Changes in streamflow timing in the western United States in recent decades." USGS Fact Sheet 2005-3018, March 2005. <http://pubs.usgs.gov/fs/2005/3018>

HDR, MHM, URS, & Wood Rodgers. August 2011. Pre-Design Formulation Report Sutter Butte Flood Control Agency Feather River West Levee Project Segments 1 through 7.

Hickey, John T., et al. Synthetic Rain Flood Hydrology for the Sacramento and San Joaquin River Basins. Journal of Hydrologic Engineering 7.3 (2002): 195-208.

Hickey, John T., et al. Reservoir Simulations of Synthetic Rain Floods for the Sacramento and San Joaquin River Basins. Journal of Water Resources Planning and Management 129 (2003): 443-457.

ICF International. July 2011. Sutter Basin Feasibility Study Environmental Without-Project Conditions Report.

Kleinfelder Inc. September 2009. Preliminary Problem Identification and Conceptual Alternatives Analysis Report, Feather River West Levee Evaluation, Thermalito Afterbay to Yuba City, Butte and Sutter Counties, California.

MWH Americas, Inc. August 2010. Sutter Basin Feasibility Study Nonstructural Flood Risk Management Alternative Report.

National Oceanic and Atmospheric Administration (NOAA), NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 6 Version 2.0, May 2011.

Nolte and Associates, “Sutter County Master Drainage Plan. Sutter County, California”, March 2002.

Sutter County, GIS layer of County waterways, Obtained from Jarvis Jones, GIS Analyst for Sutter County, 25 April 2011.

Sutter County, Sutter County General Plan Draft Environmental Impact Report, Prepared by PBS&J, September 2010.

Sutter County, Master Drainage Study for Sutter County, Prepared by Nolte & Associates, September 1979.

Sutter County As-Built Drawings, Installation of Gilsizer Slough Bank Revetment Projects GIL-18, GIL-19, GIL-20, and GIL-21, Prepared by Von Geldern Engineering Company, June 2008.

Sutter County As-Built Drawings, Installation of Gilsizer Slough Bank Revetment Projects GIL-7, GIL-8, GIL-9, GIL-10, GIL-11, and GIL-12.

Sutter County As-Built Drawings, Installation of Gilsizer Slough Bank Revetment Projects GIL-1, GIL-2, GIL-3, GIL-4, GIL-5 and GIL-6, Prepared by Von Geldern Engineering Company, April 2008.

Sutter Butte Flood Control Agency, Hydraulic Design Support for USACE Feasibility Study F3 Phase, Sutter Basin FLO-2D Modeling, Prepared by Peterson Brustad Inc., March 2011.

Sutter Butte Flood Control Agency (SBFCA), Feather River Levee Improvement Program – Appendix F-2, December 2010.

USDA. National Resource Conservation Service (NRCS), Soils data acquired from the NRCS Soils Datamart, 23 May 2011.

USDA. Soil Conservation Service, Guide for Selecting Roughness Coefficient “n” Values for Channels, December 1963.

USGS, Office of Water Data Coordination. “Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Subcommittee, Interagency Advisory

Committee on Water Data", Reston, Virginia, revised September 1981, editorial corrections March 1982.

USGS. Digital Elevation Model (DEM) Datasets, Published on 17 September 2001.

USGS. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains, USGS Water Supply Paper 2339, G.J. Arcement Jr. and V.R. Schneider.

U.S. Department of the Interior, Policy and Administration, Bureau of Reclamation, Denver, Colorado (Reclamation, 2011). "Reclamation: Managing Water in the West," SECURE Water Act Section 9503© - Reclamation Climate Change and Water, Report to Congress, 2011. <http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf>

Previous Studies and Reports on Cherokee Canal

California Department of Water Resources. Water Data Library (WDL), Cherokee Canal at Richvale data. Site visited August 2010. <http://www.water.ca.gov/waterdatalibrary/docs/Hydstra/index.cfm?site=A02984>

California Department of Water Resources. Surface Water Flow, Bulletin No. 130-61 to Bulletin No. 130-75, for Northeastern California for water years 1961 to 1975, Station A02984, Cherokee Canal near Richvale.

California Department of Water Resources. Peak flow data request for Station A02984, Cherokee Canal near Richvale. Site visited August 2010. http://www.nd.water.ca.gov/Data/index.cfm

California Department of Water Resources. Memorandum: "Cherokee Canal," from G. Donald Meixner, Retired Annuitant, to George T. Qualley, Chief, Division of Flood Management. 12 October 1989.

State of California Department of Water Resources. Proposed Mitigated Negative Declaration and Draft Initial Study, Cherokee Canal Corridor Management Strategy Pilot Project: Phase I, Sediment Removal. June 24, 2009. Site visited August 2010. http://www.water.ca.gov/floodmgmt/fmo/docs/Draft_Initial_Study-Cherokee_Canal_CMS_Pilot_Project-Phase_I_Sediment_Removal.pdf

Central Valley Flood Protection Board, May 16, 2008 Meeting Agenda, Item 10: "Cherokee Canal Rehabilitation." Site visited August 2010. http://www.cvfpb.ca.gov/meetings/2008/5-16-2008Item10-CherokeeCanalRehabilitation.pdf

Butte County Board of Education. Excerpt "A Splash of Cherokee Watershed History" from History of Butte County by Joseph F. McGie. 1983. Site visited August 2010. <http://www.cherokeewatershed.org/nodes/aboutwatershed/reports/documents/eds_foreward.pdf>

USACE. Unpublished study to compute SPF on Cherokee Canal for the Corps report, “Standard Project Floods, Sacramento River and Tributaries Above Ord Ferry,” dated 15 March 1963.

USACE. Memorandum for Record: “Inspection of Cherokee Canal (Maintenance Area 13).” 24 May 1989. (Information on March 1989 levee overtopping.).

USACE. Memorandum for Record: “PL 84-99 Site Inspection, Cherokee Canal, Butte County, California.” 5 July 1995. (Information on waterside levee slip of January 1995).

URS Corporation for U.S. Army Corps of Engineers, Sacramento District. “Section 1135 Hydrologic, Hydraulic, and Sediment Yield/Transport Study Final Report, Cherokee Canal, Butte County, California.” January 2003.

U.S. Army Corps of Engineers Previous Studies

USACE. “Lower Feather River Floodplain Mapping Study, Feather River Hydrology and Reservoir Modeling, Appendix A.”, 2004.

USACE. “Sutter County Feasibility Study, Hydrology, Appendix B, Synthetic Hydrology and Reservoir Operations Technical Documentation”, April 2004.

USACE. “Yuba River Basin Project General Reevaluation Report, Appendix A, Synthetic Hydrology and Reservoir Operations Technical Documentation”, April 2004, Revised in June 2008.

USACE. 2008. "Yuba River Basin Project General Reevaluation Report: Appendix A Synthetic Hydrology and Reservoir Operations Technical Documentation”.

USACE. 2008. California State Central Valley Flood Protection Board, and the Sutter-Butte Flood Control Agency. "Sutter Basin, California General Investigation Feasibility Study Revised Project Management Plan”.

USACE. March 2011. Columbia River Treaty 2014/2024 Review Program, Phase 2A Flood Risk Assessment Report, Draft Appendix E, “Climate Change”.

USACE. 1977. San Joaquin River Basin, California; Hydrology Office Report, Lower San Joaquin River. Sacramento District. Sacramento, California.

USACE. 1993. Sacramento River Flood Control Project, Hydrology Office Report. Sacramento District. Sacramento, California.

USACE. 1990. Sacramento River Flood Control Systems Evaluation, Phase II, Initial Appraisal Report, Marysville/Yuba City Area. Sacramento District, Sacramento, CA.

USACE. July 1999. Sutter Basin, CA, Expedited Reconnaissance Study for Flood Damage Reduction, Section 905(b) (WRDA 86) Analysis. Sacramento District, Sacramento, CA.

USACE. August 1970, Revised February 2005. “Oroville Dam and Lake, Feather River, California, Water Control Manual”.

USACE. 29 March 2011. Sacramento River Bank Protection Project, Phase II, 80,000 Linear Feet Post Authorization Change Report, Hydraulic Appendix, Draft Final “Sea Level Change Analysis Report”.

USACE. December 2010. American River Watershed Common Features Project Natomas Basin Post-Authorization Change Report and Interim General Reevaluation Report. Sacramento District, Sacramento, CA.

USACE. January 2011. Yuba River Basin, California, Alternative Formulation Briefing F4A Milestone Conference Document. Sacramento District, Sacramento, CA.

USACE. California State Central Valley Flood Protection Board, and the Sutter-Butte Flood Control Agency. "Sutter Basin, California General Investigation Feasibility Study Revised Project Management Plan." 2008.

USACE. “Lower Feather River Floodplain Mapping Study, Feather River Hydrology and Reservoir Modeling, Appendix A.”, 2004.

USACE. “Sutter County Feasibility Study, Hydrology, Appendix B, Synthetic Hydrology and Reservoir Operations Technical Documentation”, April 2004.

USACE. “Yuba River Basin Project General Reevaluation Report, Appendix A, Synthetic Hydrology and Reservoir Operations Technical Documentation”, April 2004, corrected in June 2008.

USACE. October 2011. Environmental Site Assessment, Sutter Basin Pilot Study Preliminary Assessment of Alternatives. Sacramento District, Sacramento, CA.

Software

USACE. Flood Frequency Analysis HEC-FFA: User’s Manual. May 1992.

USACE. “Flood Frequency-Analysis, HEC-SSP, User's Manual Version 1.1”, April 2009.

USACE. “HEC-5, Simulations of Flood Control and Conservation Systems, User's Manual, version 8.0”, October 1998.

USACE. “HEC-RAS River Analysis System, User's Manual, Version 3.0”, January 2001.

USACE.   HEC-HMS Version 3.4 User’s Manual, August 2009.

<u>Sacramento and San Joaquin Rivers Comprehensive Study</u>

USACE. 1999. Sacramento and San Joaquin River Basins, California; Post-Flood Assessment. Sacramento District. Sacramento, California.

USACE. December 2002. Sacramento and San Joaquin River Basins, California, Comprehensive Study, Interim Report. Sacramento District, Sacramento, CA.

USACE. "Sacramento and San Joaquin River Basins Comprehensive Study, Technical Studies Documentation: Appendix B Synthetic Hydrology." 2002.

USACE. "Sacramento and San Joaquin River Basins Comprehensive Study, Technical Studies Documentation: Appendix C Reservoir Operations Modeling, Existing Design Operations and Reoperation Analyses." 2002.

USACE. "Sacramento and San Joaquin River Basins Comprehensive Study, Technical Studies Documentation: Appendix D Hydraulics." 2002.

USACE. "Sacramento and San Joaquin River Basins, California Comprehensive Study Interim Report." 2002.

USACE.   HEC-HMS Models for the Sacramento and San Joaquin River Basins Comprehensive Study, August 2001.

<u>Corps Policy and Guidance</u>

USACE. January 2011. Recommendations for Transforming the Current Pre-Authorization Study Process.

USACE. February 2012. Memorandum for Major Subordinate Commands. U.S. Army Corps of Engineers Civil Works Feasibility Study Program Execution and Delivery.

USACE. Engineer Manual 1110-2-1619, "Risk-Based Analysis for Flood Damage Reduction Studies." August 1996.

USACE. Engineer Manual 1110-2-1415, “Hydrologic Frequency Analysis.” 5 March 1993.

USACE. Engineer Manual 1110-2-1417: Flood-Runoff Analysis, 31 August 1994.

USACE. Engineer Regulation 1165-2-26, “Implementation of Executive Order 11988 on Flood Plain Management”, March 1984.

Legend

- Sutter Basin Study Area
- Sacramento Basin
- Watershed Boundary
- Lake or Reservoir
- Designated Floodway
- River or Stream
- City

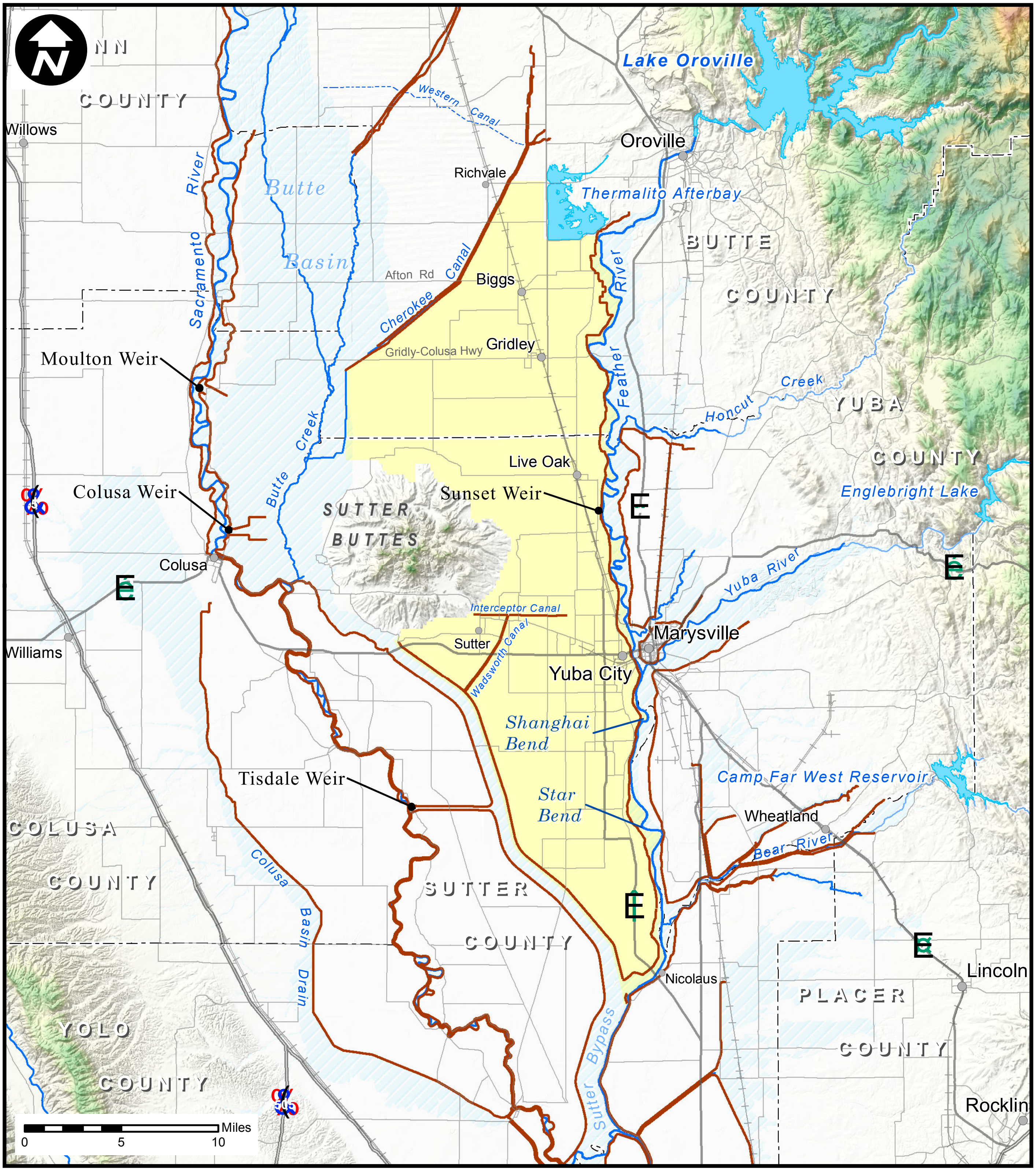
SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

SACRAMENTO RIVER WATERSHED

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012



Legend

Study Area Extent	Highway
Designated Floodway	Major Road
Lake or Reservoir	Railroad
River or Stream	County Boundary
Federal Levee	City or Town

SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

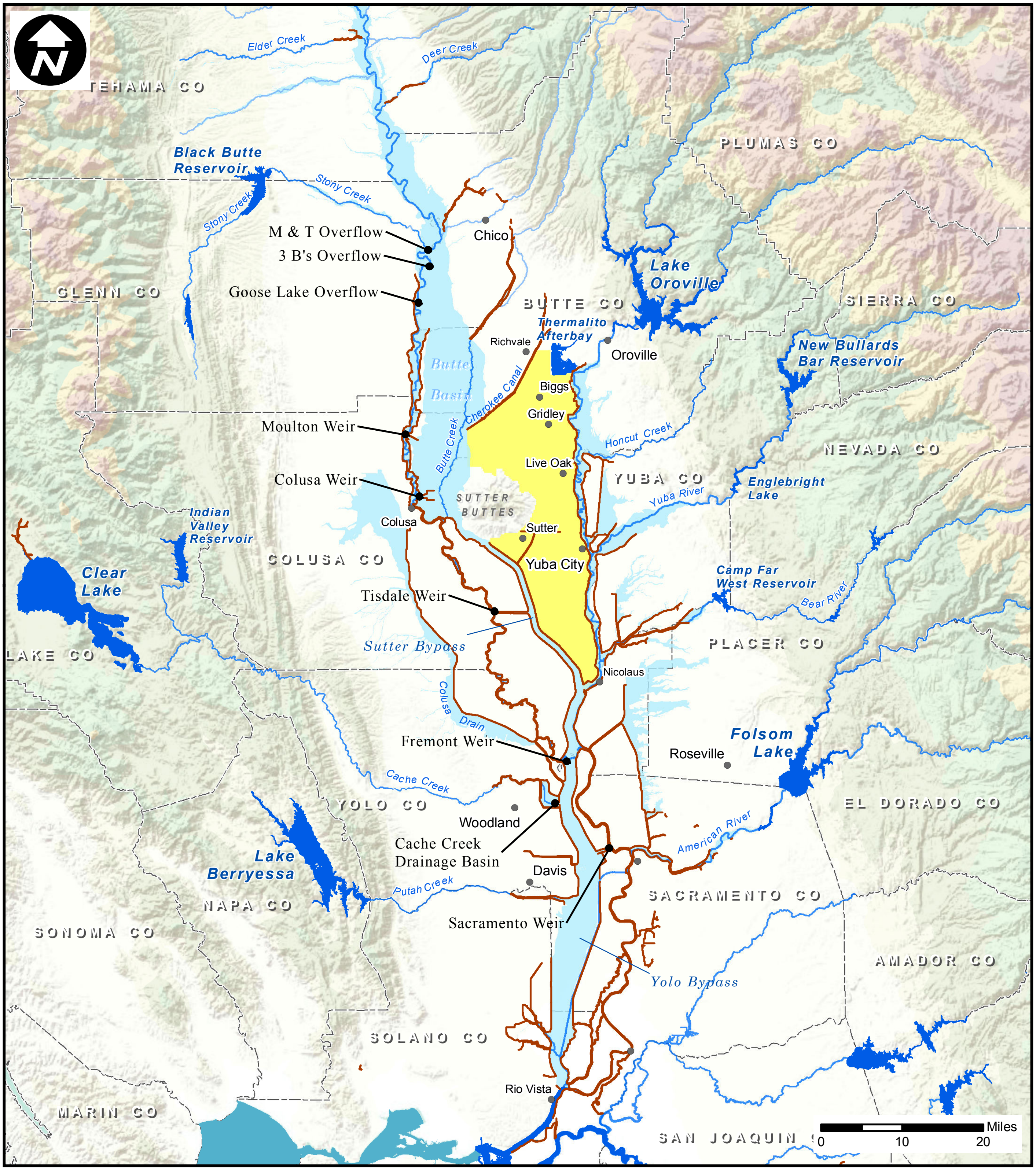
STUDY AREA

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012

PLATE 2



Legend

Study Area Extent

Designated Floodway

Lake or Reservoir

River or Stream

Federal Levee

County Boundary

City

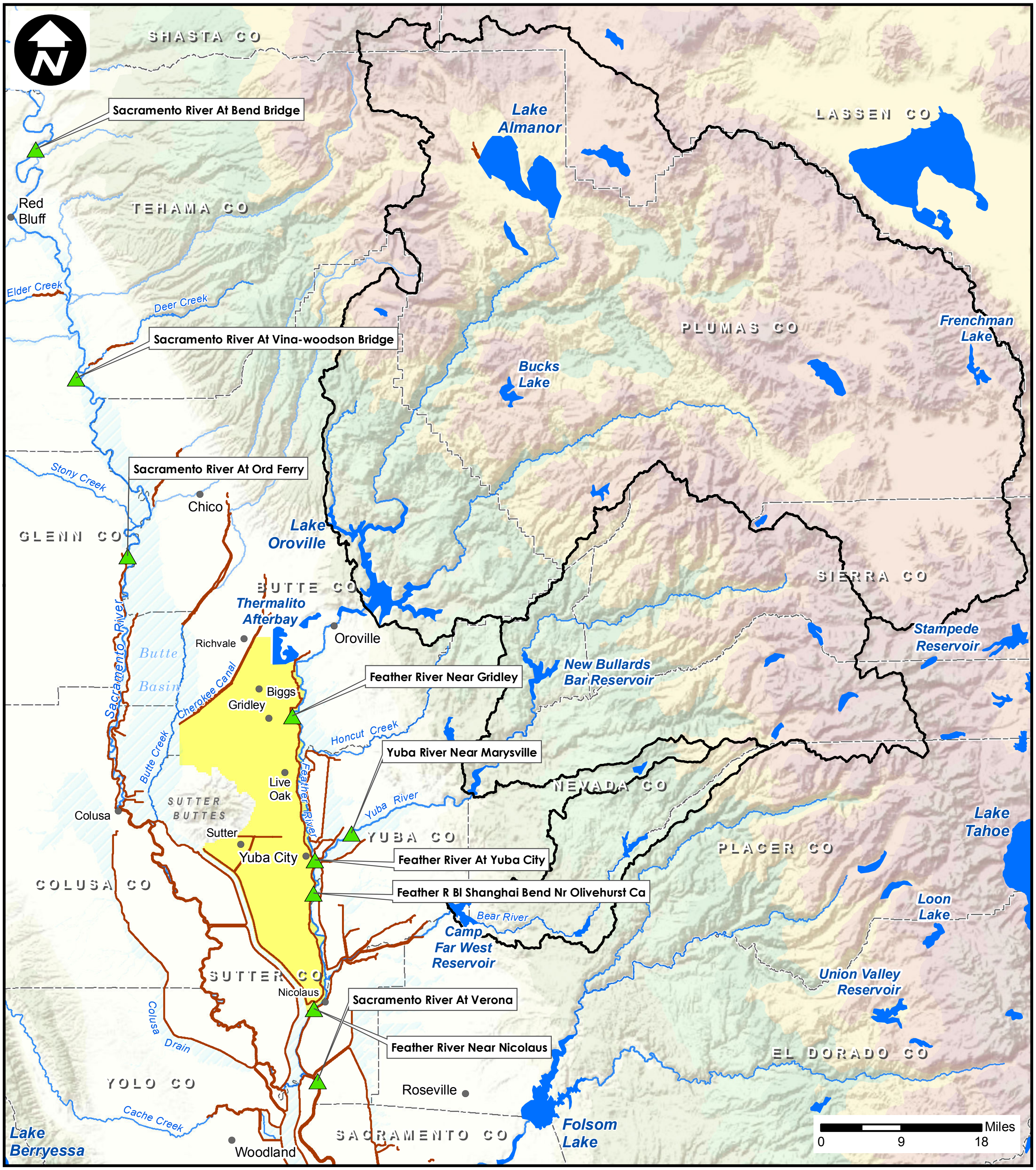
SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

SACRAMENTO RIVER FLOOD CONTROL PROJECT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012



Legend

- Stream Gage
- Study Area Extent
- Watershed Boundary
- Designated Floodway
- Federal Levee
- Lake or Reservoir
- River or Stream
- County Boundary
- City

SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

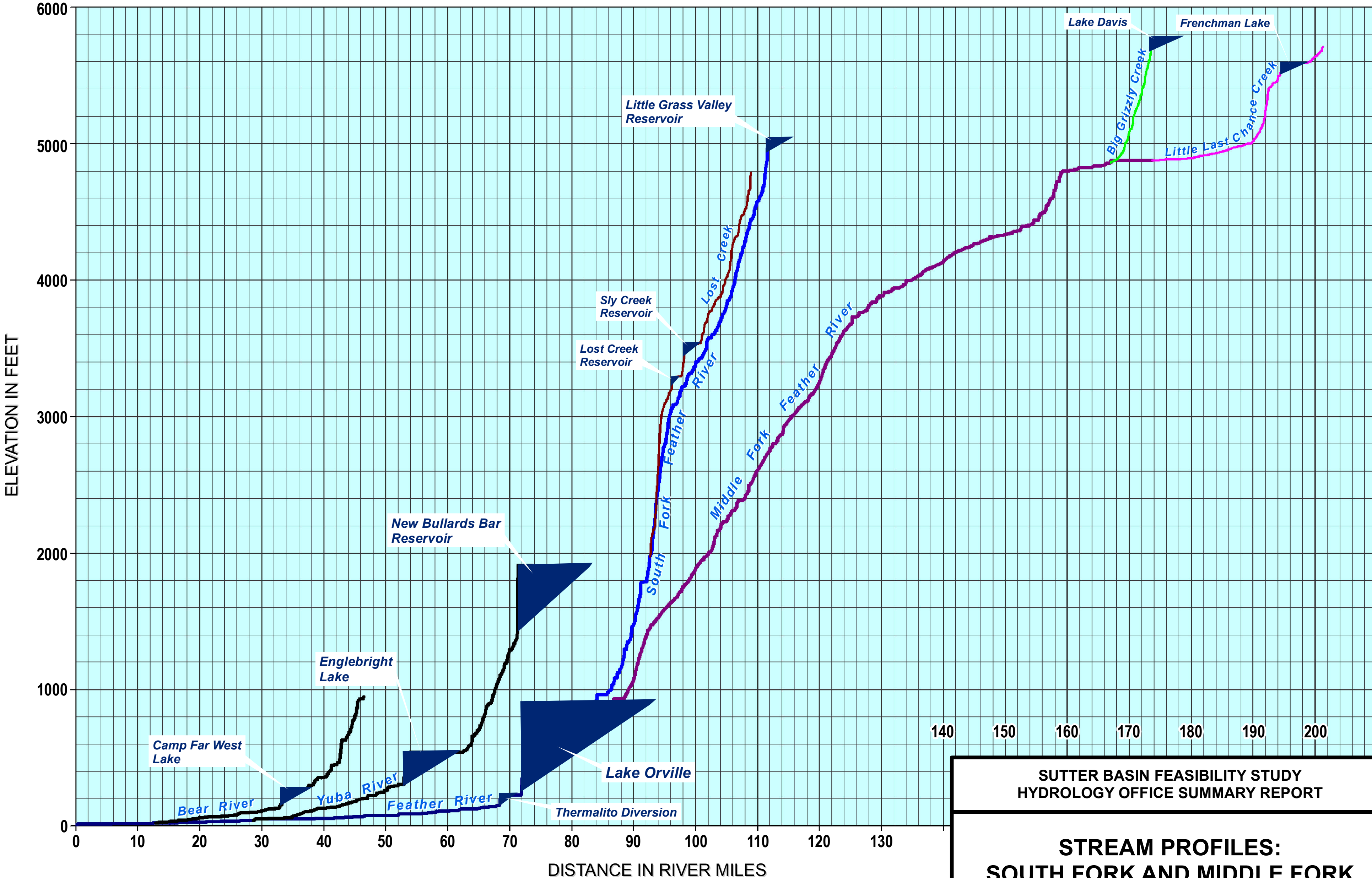
UPPER WATERSHED BASINS TOPOGRAPHY AND STREAM GAGES

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012

PLATE 4



SUTTER BASIN FEASIBILITY STUDY
HYDROLOGY OFFICE SUMMARY REPORT

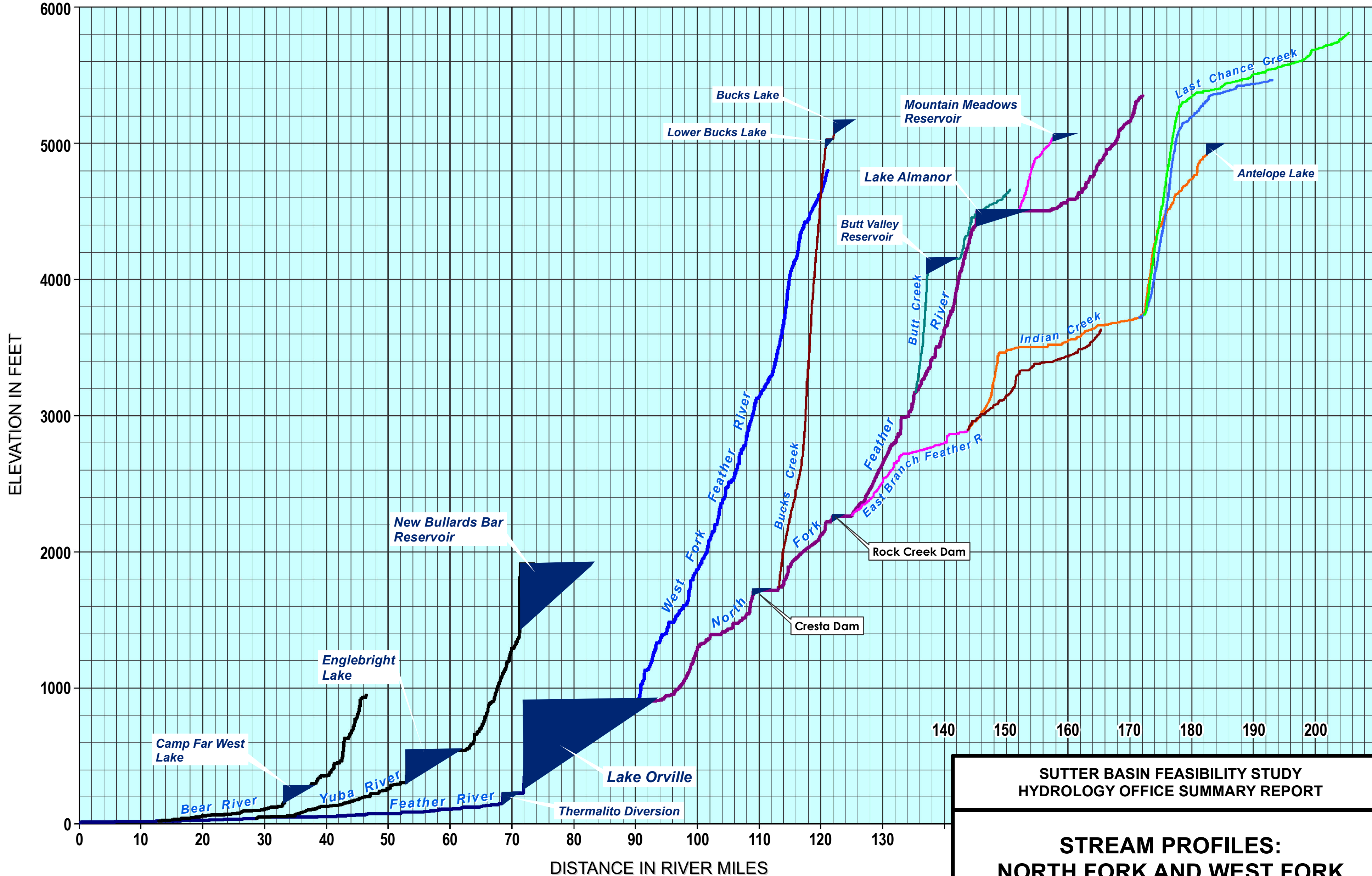
STREAM PROFILES: SOUTH FORK AND MIDDLE FORK FEATHER RIVER

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012

PLATE 5.1



SUTTER BASIN FEASIBILITY STUDY
HYDROLOGY OFFICE SUMMARY REPORT

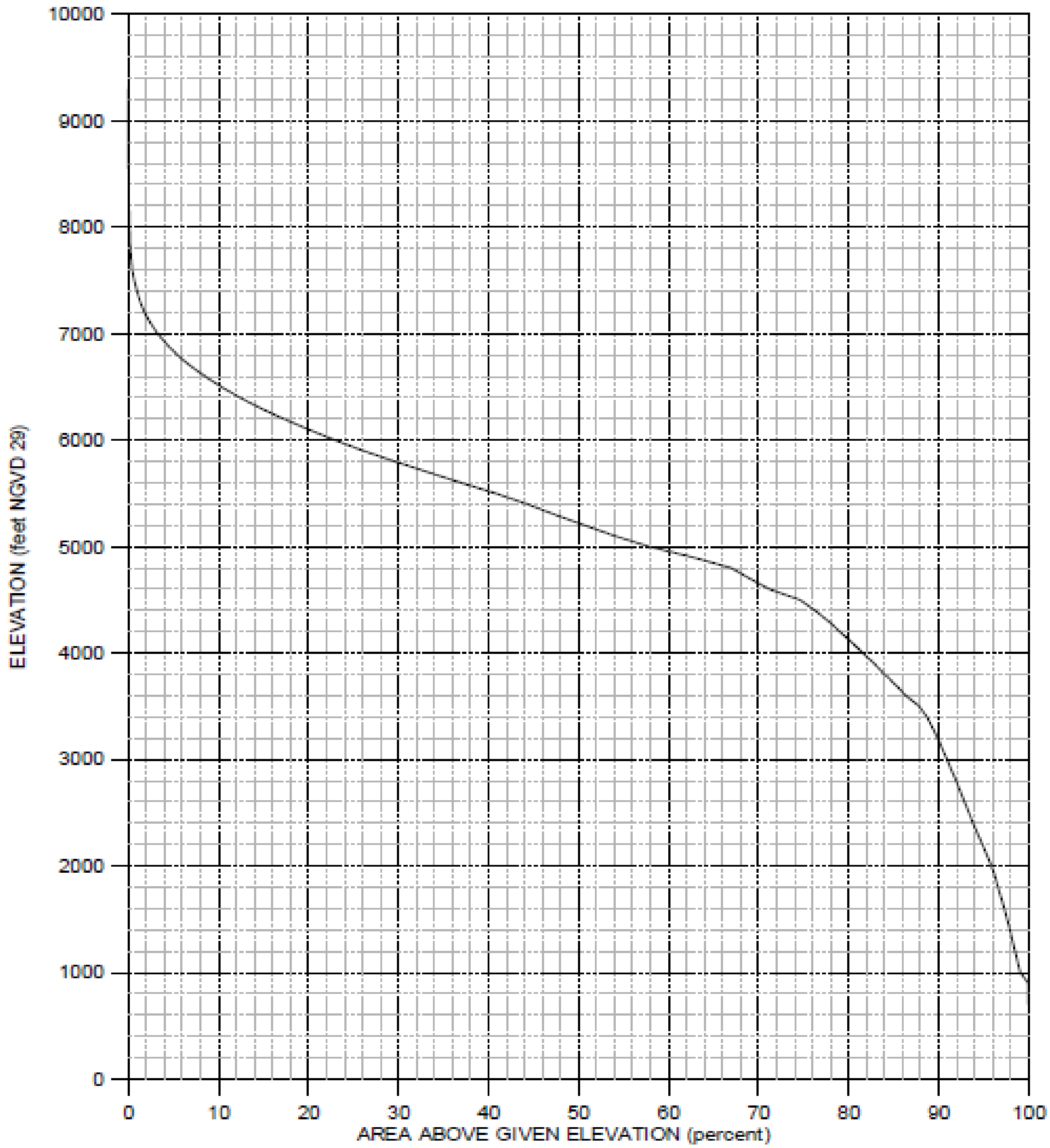
STREAM PROFILES: NORTH FORK AND WEST FORK FEATHER RIVER

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012

PLATE 5.2



NOTES:

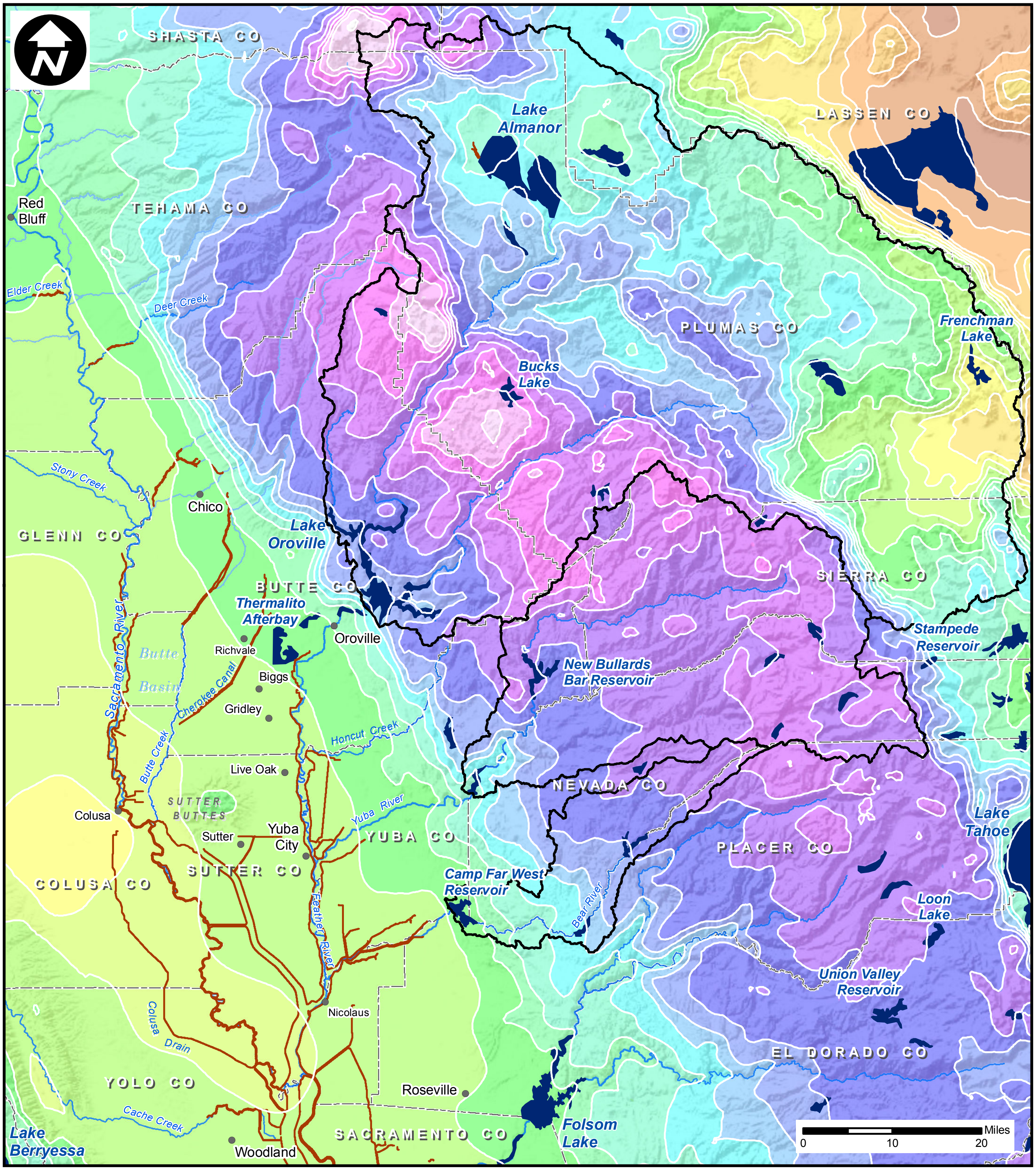
Watershed above Oroville Dam (3,602 square miles)

Source: Oroville Water Control Manual, Revised Feb 2005

SUTTER BASIN FEASBILITY STUDY
SUTTER BASIN, CALIFORNIA

AREA-ELEVATION CURVE

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Legend

Watershed Boundary

Federal Levee

Lake or Reservoir

River or Stream

County Boundary

City

SUTTER BASIN PILOT FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

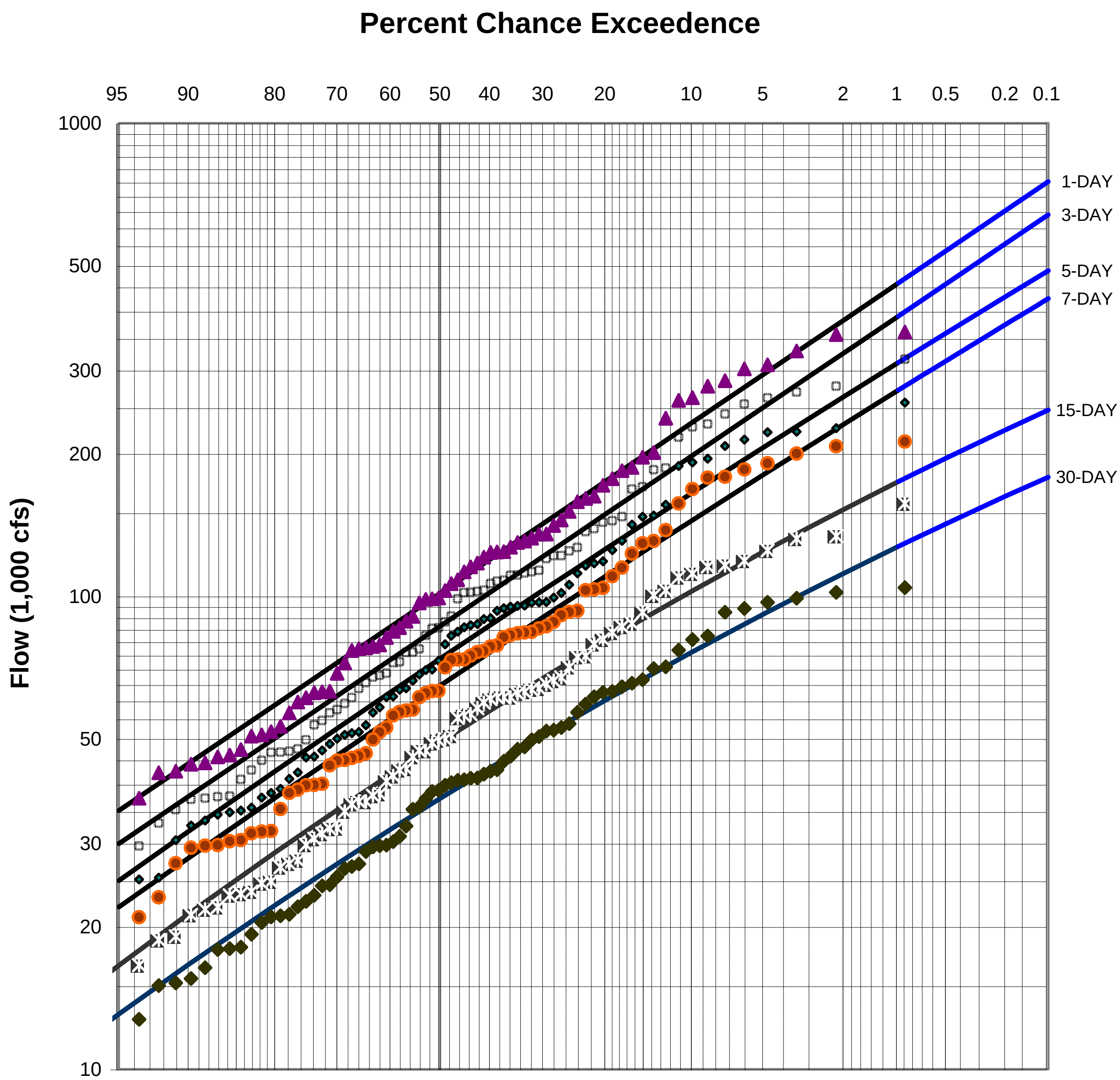
**UPPER WATERSHED BASINS
NORMAL ANNUAL PRECIPITATION
AND CLIMATOLOGICAL GAGES**

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012

PLATE 7



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	5.009	0.281	0.0
3-day	4.939	0.281	0.0
5-day	4.866	0.279	-0.1
7-day	4.809	0.278	-0.1
15-day	4.680	0.267	-0.3
30-day	4.562	0.258	-0.3

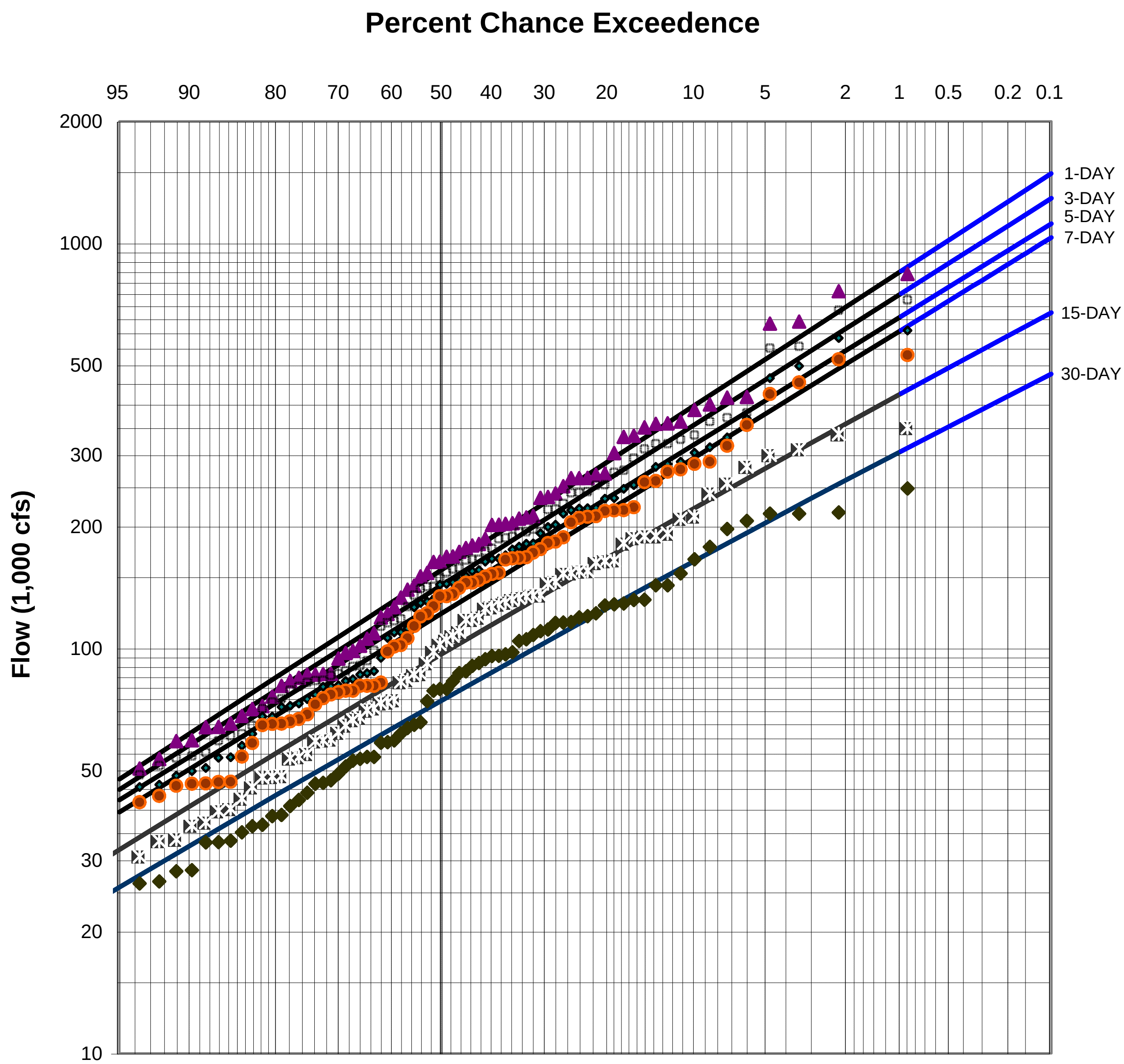
NOTES:

1. Adjusted USGS gage 11388700 to account for daily change in storage at upstream reservoirs (potential channel, out-of-channel, or storage losses neglected).
2. WY 1977 censored as low outlier.
3. Median plotting positions.
4. Drainage area: approx. 12,050 sq. mi.
5. Period of record: 1922-1997.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
SACRAMENTO RIVER AT ORD FERRY (LATITUDE)
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	5.196	0.316	0.0
3-day	5.158	0.308	0.0
5-day	5.120	0.301	0.0
7-day	5.088	0.300	0.0
15-day	4.983	0.287	-0.1
30-day	4.869	0.274	-0.2

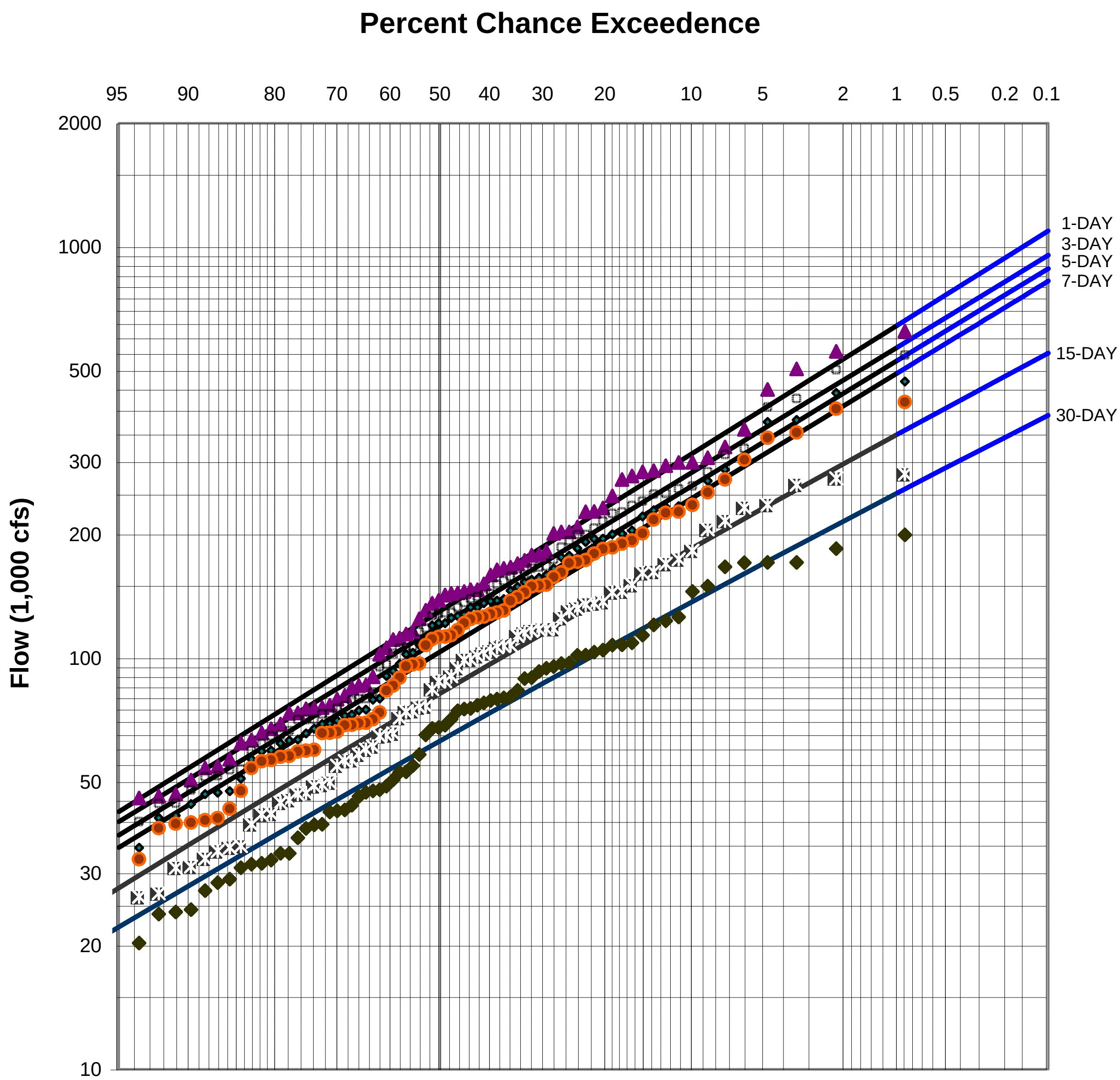
NOTES:

1. Adjusted USGS gage 11447500 to account for daily change in storage at upstream reservoirs (potential channel, out-of-channel, or storage losses neglected).
2. WY 1977 censored as low outlier.
3. Median plotting positions.
4. Drainage area: approx. 26,150 sq. mi.
5. Period of record: 1922-1997.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
SACRAMENTO RIVER AT SACRAMENTO (LATITUDE)
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	5.117	0.298	0.0
3-day	5.081	0.291	0.0
5-day	5.048	0.291	0.0
7-day	5.018	0.291	0.0
15-day	4.912	0.281	-0.1
30-day	4.796	0.269	-0.2

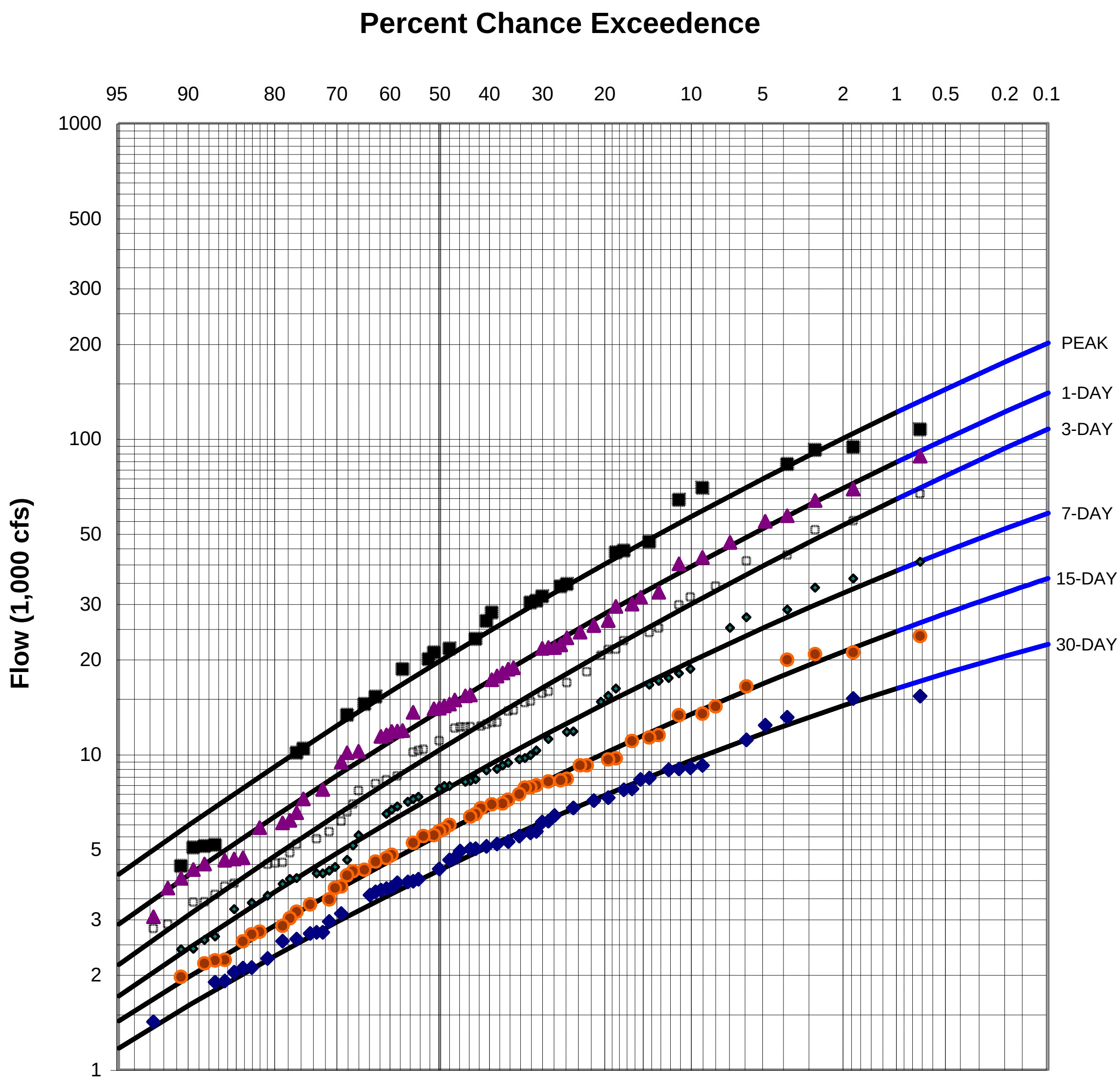
NOTES:

1. Adjusted USGS gage 11425500 to account for daily change in storage at upstream reservoirs (potential channel, out-of-channel, or storage losses neglected).
2. WY 1977 censored as low outlier.
3. Median plotting positions.
4. Drainage area: approx. 21,251 sq. mi.
5. Period of record: 1922-1997.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
SACRAMENTO RIVER AT VERONA (LATITUDE)
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED STATISTICS:

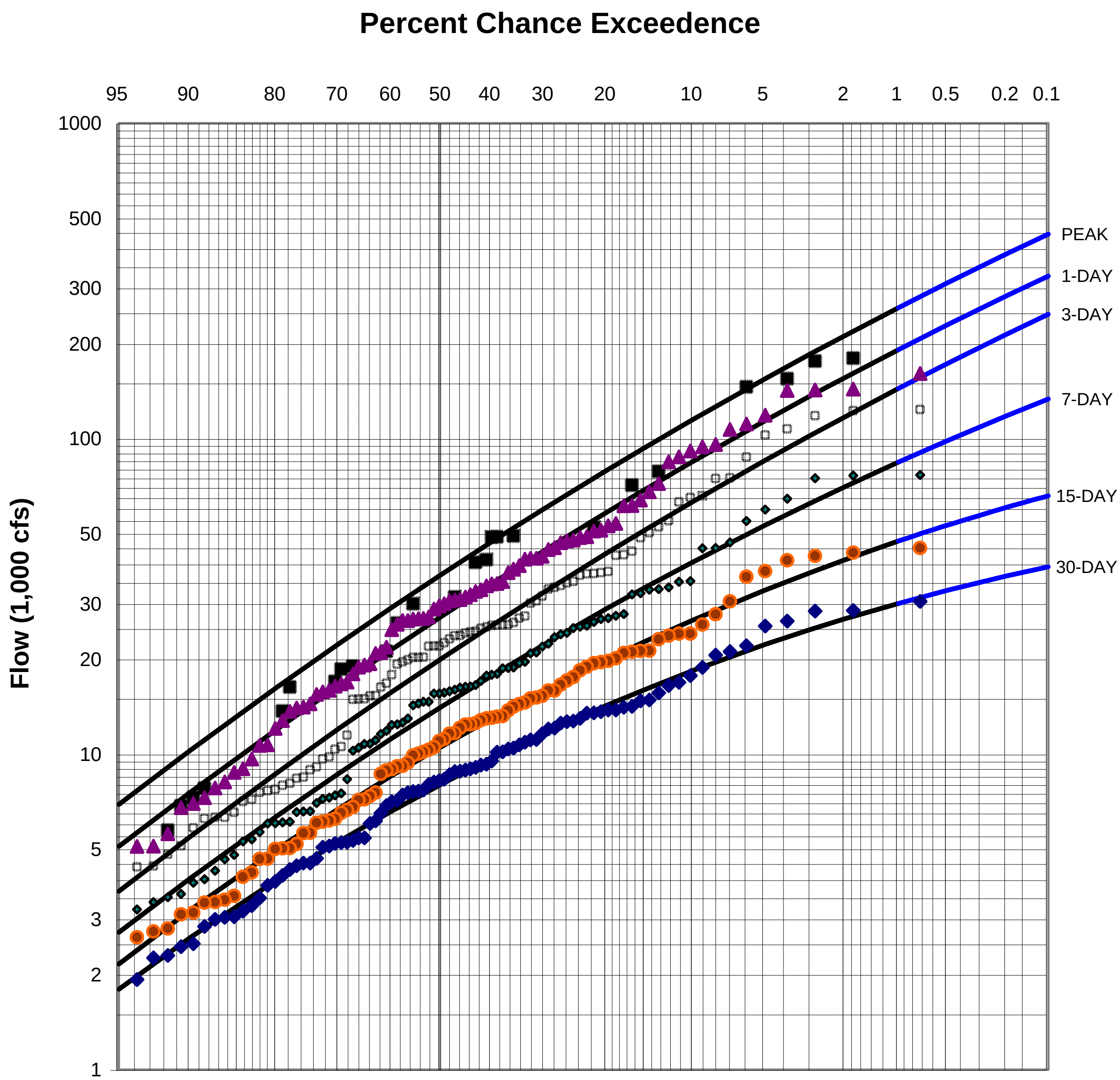
	Mean	Std.Dev.	Skew
Peak	4.280	0.383	-0.3
1-day	4.122	0.383	-0.3
3-day	3.999	0.386	-0.3
7-day	3.858	0.357	-0.4
15-day	3.727	0.327	-0.4
30-day	3.611	0.306	-0.5

NOTES:
1. Statistics adjusted based on correlation with Yuba River near Marysville station (94 years).
2. Median plotting positions.
3. Drainage Area: 489 sq. mi.
4. Period of record: 1938-1997.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
NORTH YUBA AT NEW BULLARDS BAR DAM
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED STATISTICS:

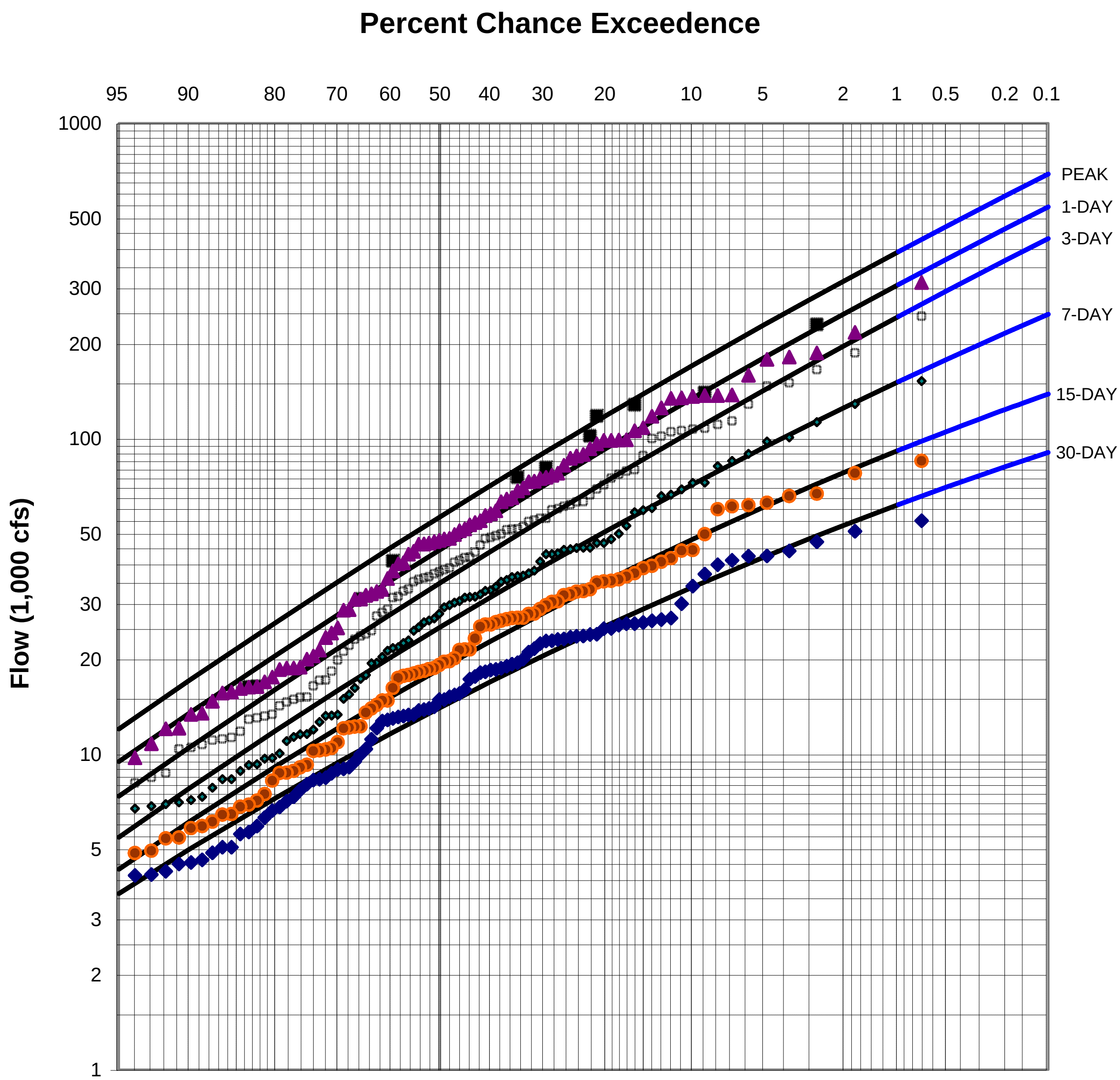
	Mean	Std.Dev.	Skew
Peak	4.550	0.411	-0.3
1-day	4.417	0.411	-0.3
3-day	4.283	0.416	-0.3
7-day	4.125	0.394	-0.4
15-day	3.989	0.364	-0.6
30-day	3.867	0.337	-0.7

NOTES:
1. Median plotting positions.
2. Peak data available for 25 years of record.
3. Drainage area: 1,339 sq. mi.
4. Period of record: 1904-1997.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
YUBA RIVER NEAR MARYSVILLE
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
Peak	4.743	0.390	-0.2
1-day	4.639	0.390	-0.2
3-day	4.533	0.392	-0.2
7-day	4.387	0.377	-0.3
15-day	4.250	0.351	-0.4
30-day	4.129	0.326	-0.4

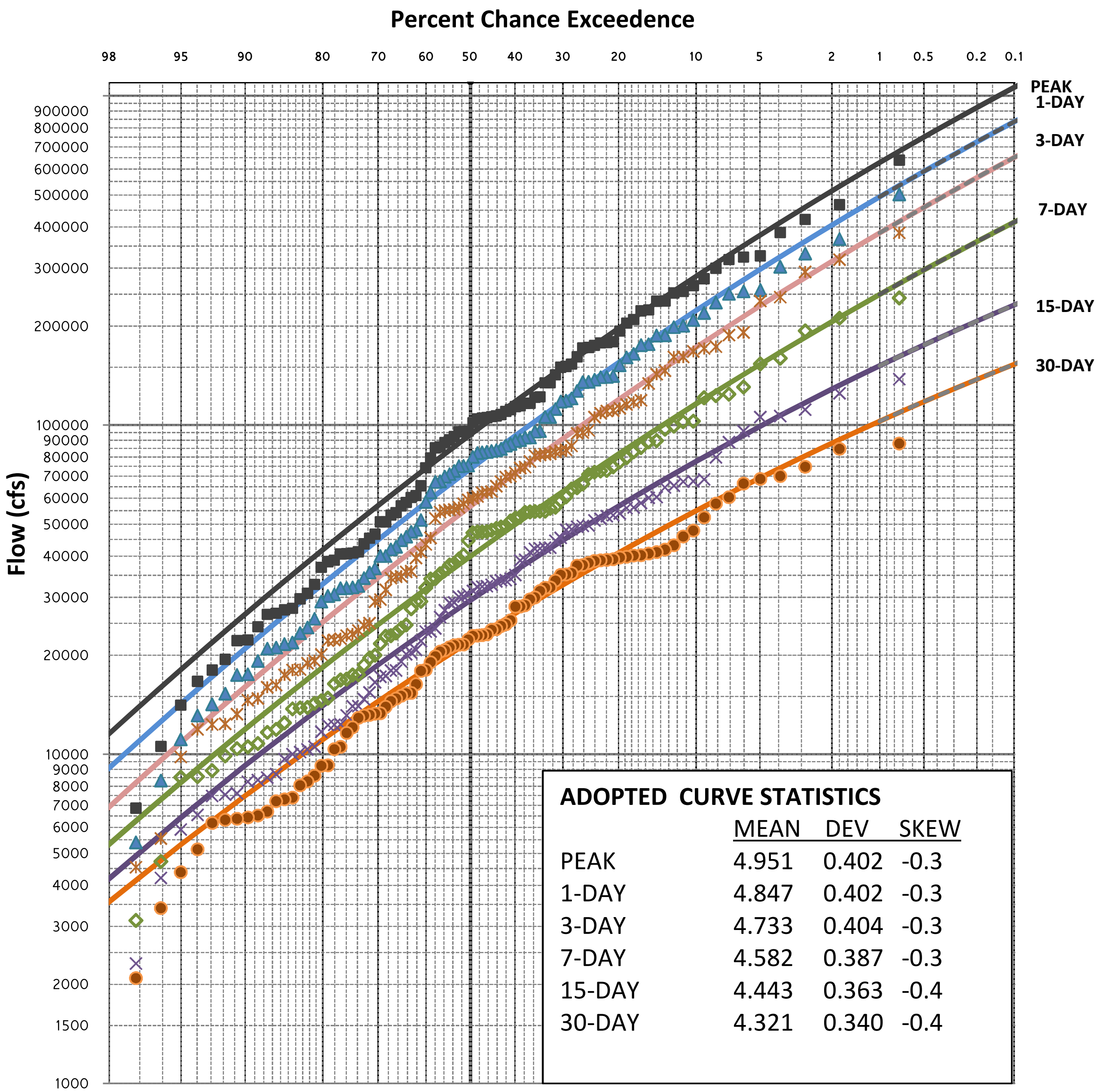
NOTES:

1. Median plotting positions.
2. Peak data available for 11 years of record.
3. Drainage area: 3,624 sq. mi.
4. Period of record: 1901-1997.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
FEATHER RIVER AT OROVILLE DAM
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED CURVE STATISTICS

	MEAN	DEV	SKEW
PEAK	4.951	0.402	-0.3
1-DAY	4.847	0.402	-0.3
3-DAY	4.733	0.404	-0.3
7-DAY	4.582	0.387	-0.3
15-DAY	4.443	0.363	-0.4
30-DAY	4.321	0.340	-0.4

NOTES:

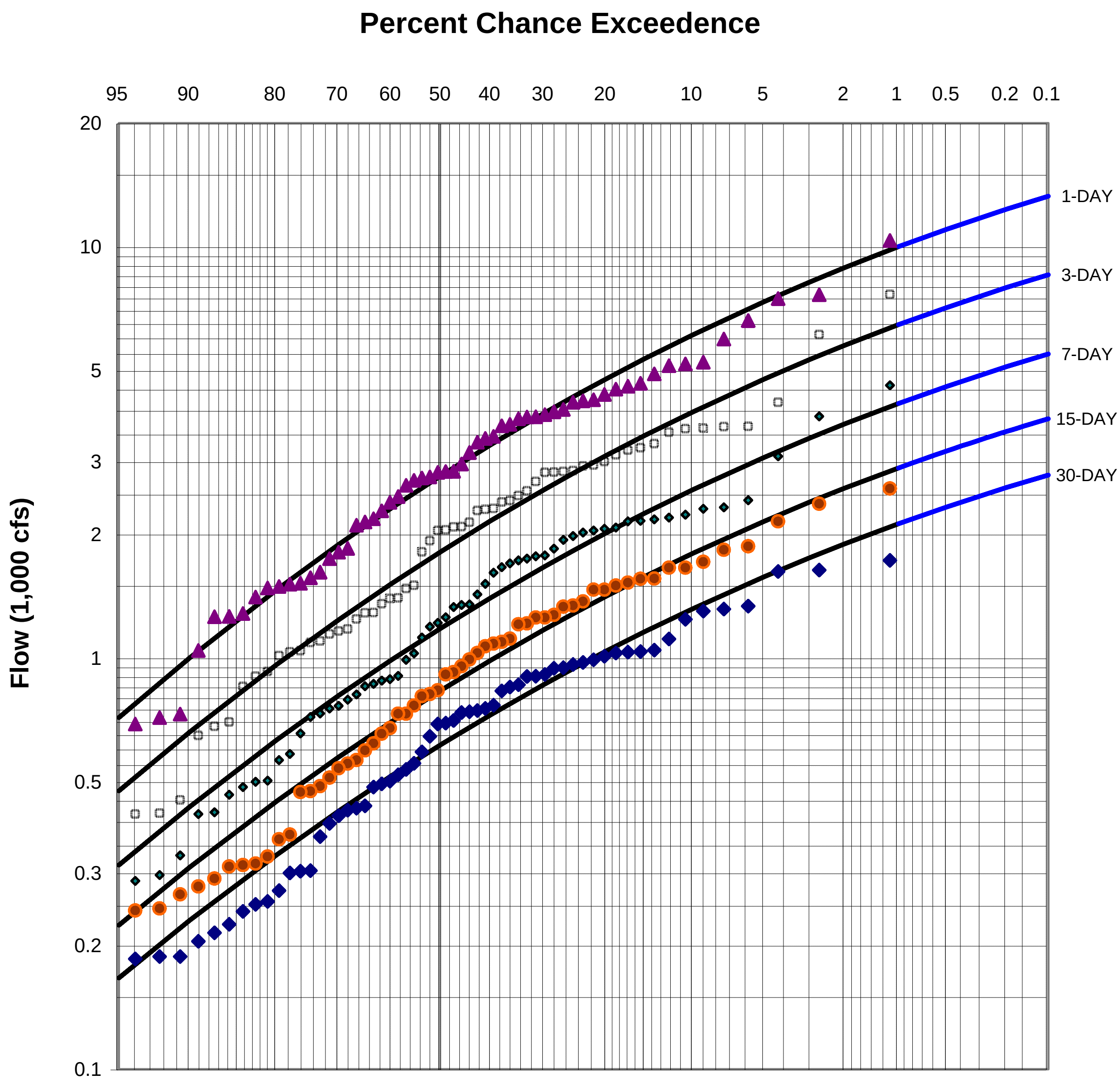
1. Median plotting positions.
2. Computed Probability
3. Drainage area: 5313 sq. mi.
4. 94 years of record (1904 to 1997)

MODIFIED BY BJW MAY 2002

SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

RAINFLOOD FREQUENCY CURVES
FEATHER RIVER AT SHANGHAI BEND
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	3.414	0.311	-0.6
3-day	3.230	0.308	-0.6
7-day	3.044	0.305	-0.6
15-day	2.893	0.302	-0.6
30-day	2.761	0.300	-0.6

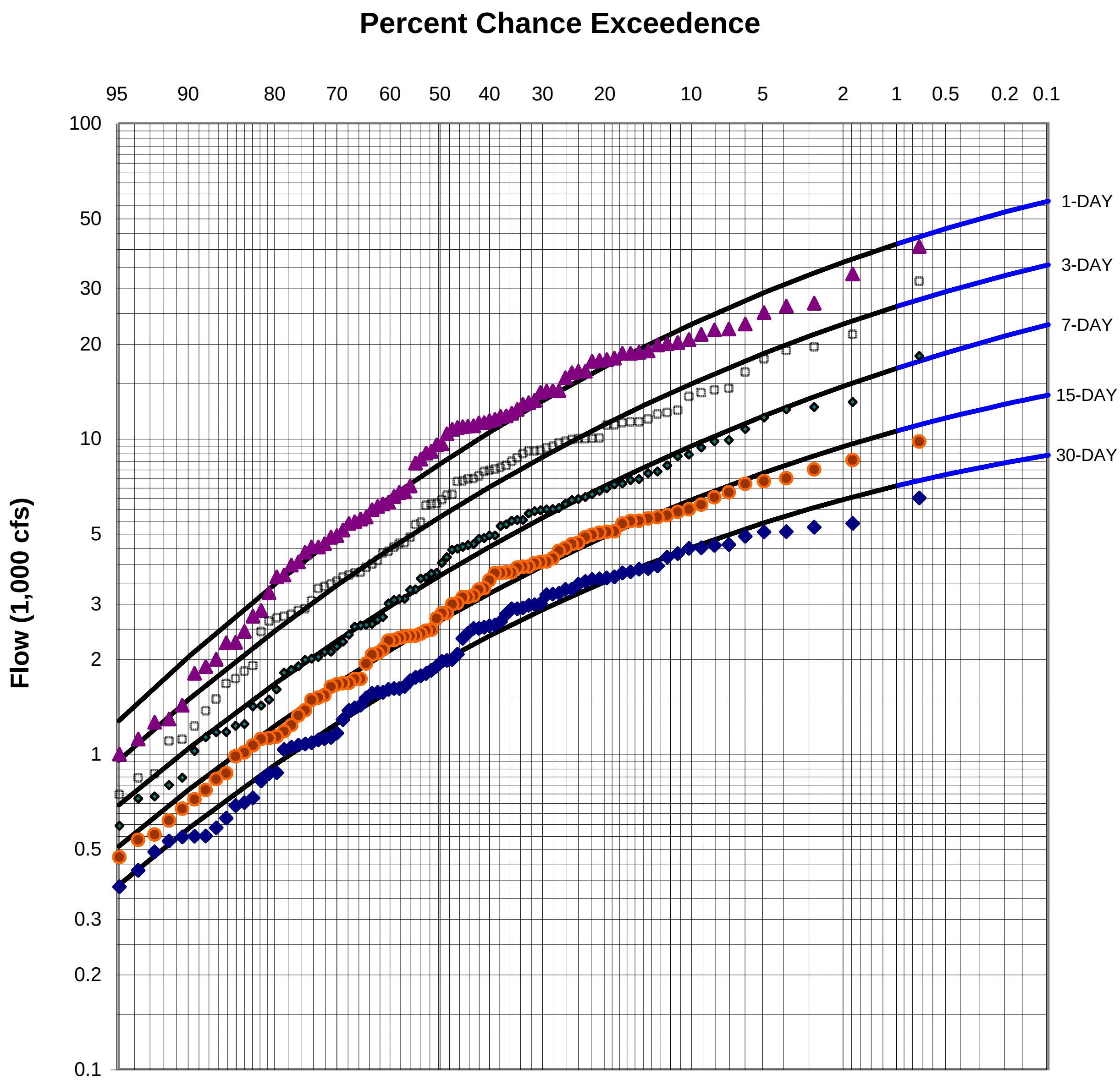
NOTES:

1. Adjusted USGS gage 11418500 to account for daily change in storage at upstream reservoir (potential channel, out-of-channel, or storage losses neglected).
2. WY 1977 censored as low outlier.
3. Median plotting positions.
4. Drainage area: 84.6 sq. mi.
5. Period of record: 1936-1997.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
DEER CREEK NEAR SMARTVILLE
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	3.872	0.420	-0.7
3-day	3.707	0.399	-0.7
7-day	3.527	0.380	-0.7
15-day	3.379	0.367	-0.8
30-day	3.244	0.357	-0.9

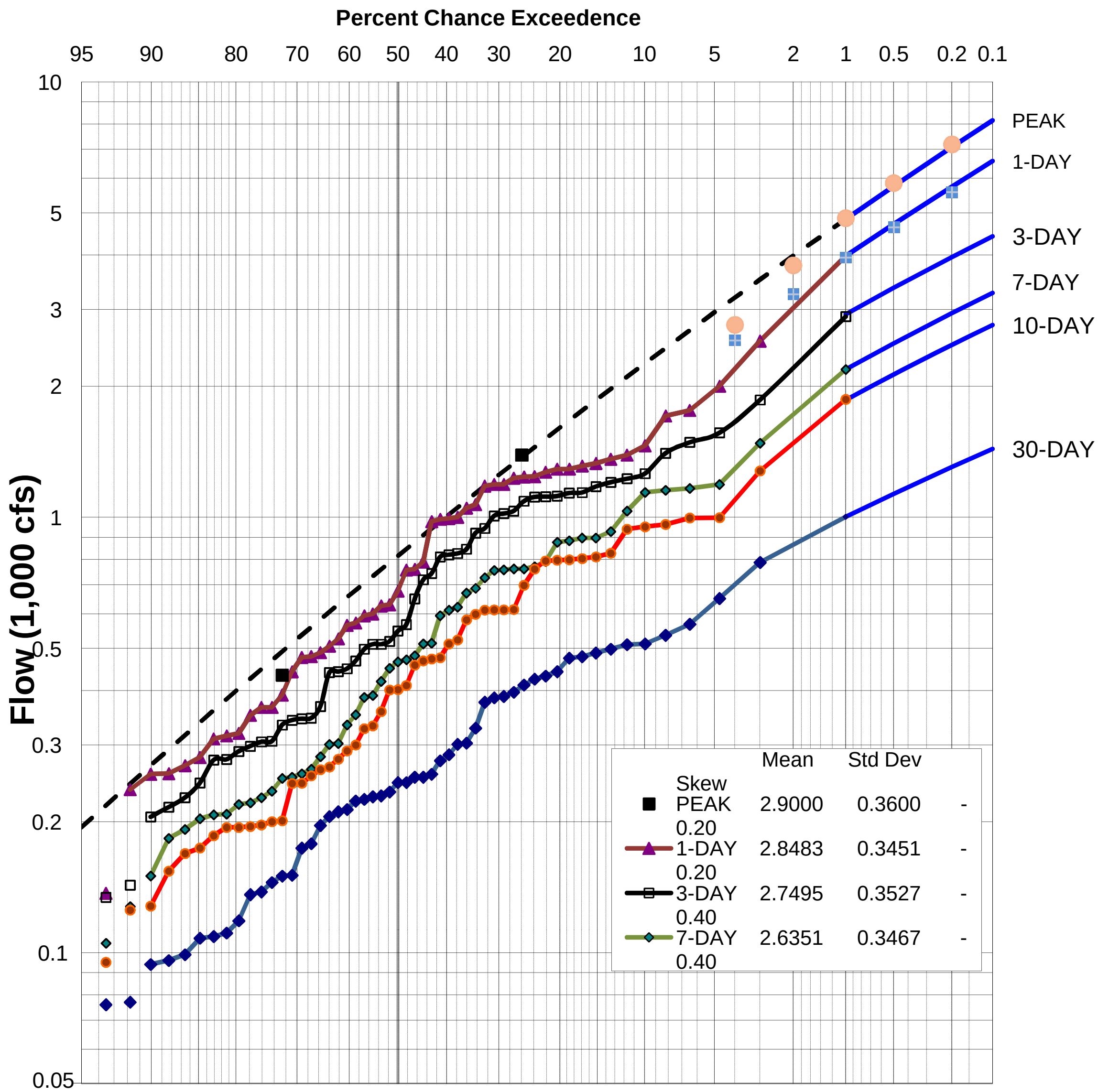
NOTES:

1. Adjusted USGS gage 11424000 to account for daily change in storage at upstream reservoirs (potential channel, out-of-channel, or storage losses neglected).
2. Statistics adusted based on correlation with Van Trent (1906-27) and Yuba R at Smartville (1928).
3. Median plotting positions.
4. Drainage area: 292 sq. mi.
5. Period of record: 1906-1998.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
BEAR RIVER NEAR WHEATLAND
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Notes:

1. Recorded flows use median plotting positions for the 56 years of record from 1939 to 1996.
2. Drainage area about 96 sq. mi. for DWR Station A05929.
3. Modeled values from SBFCA HMS model June 2012 with precipitation reflecting The 1-, 3-, 7-, 10-, and 30-day data was plotted to extend the historical data up to the 0.1-percent exceedance frequency of the estimated best fit curve.
4. The peak flow curve was manually adjusted to best fit the historical and modeled data and the 1-day volume curve. Model Runs reflect 10 Year Flows in the Sutter Bypass with storm precipitation reflecting the frequency of the flows reflected on the flow volume frequency curve.
5. The plotted curves to the right of the 1-percent exceedance frequency are manually

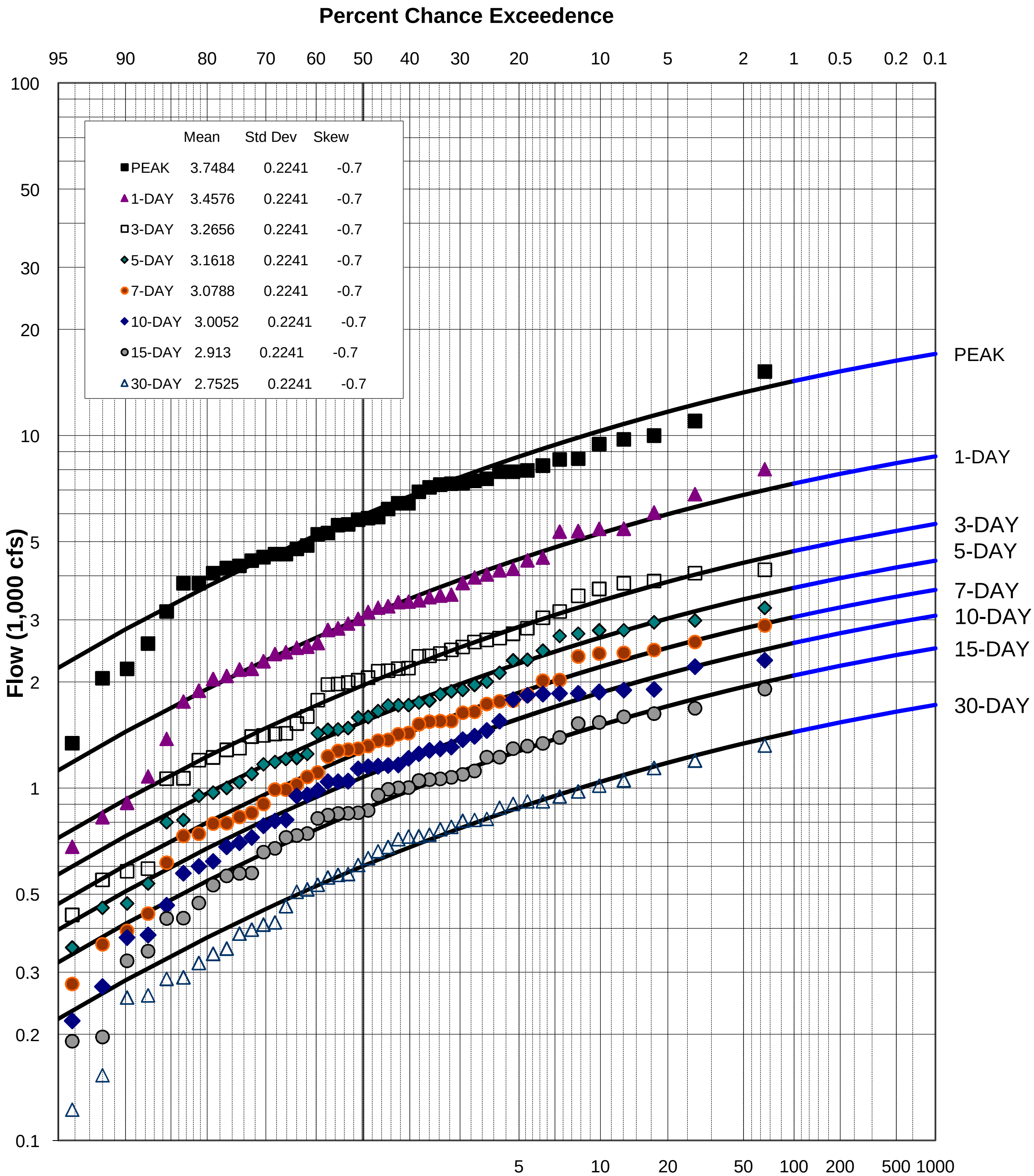
RAIN FLOOD FREQUENCY CURVES
UNREGULATED CONDITIONS

WADSWORTH CANAL NR SUTTER
SACRAMENTO RIVER BASIN.

WATER YEARS 1939 ~ 1996

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

PLATE 17



SUTTER BASIN, CALIFORNIA

Sutter Basin Hydrology Study

CHEROKEE CANAL NEAR RICHVALE, CA

RAIN FLOOD FREQUENCY CURVES

WATER YEARS 1961-2006

U.S. ARMY CORPS OF ENGINEERS

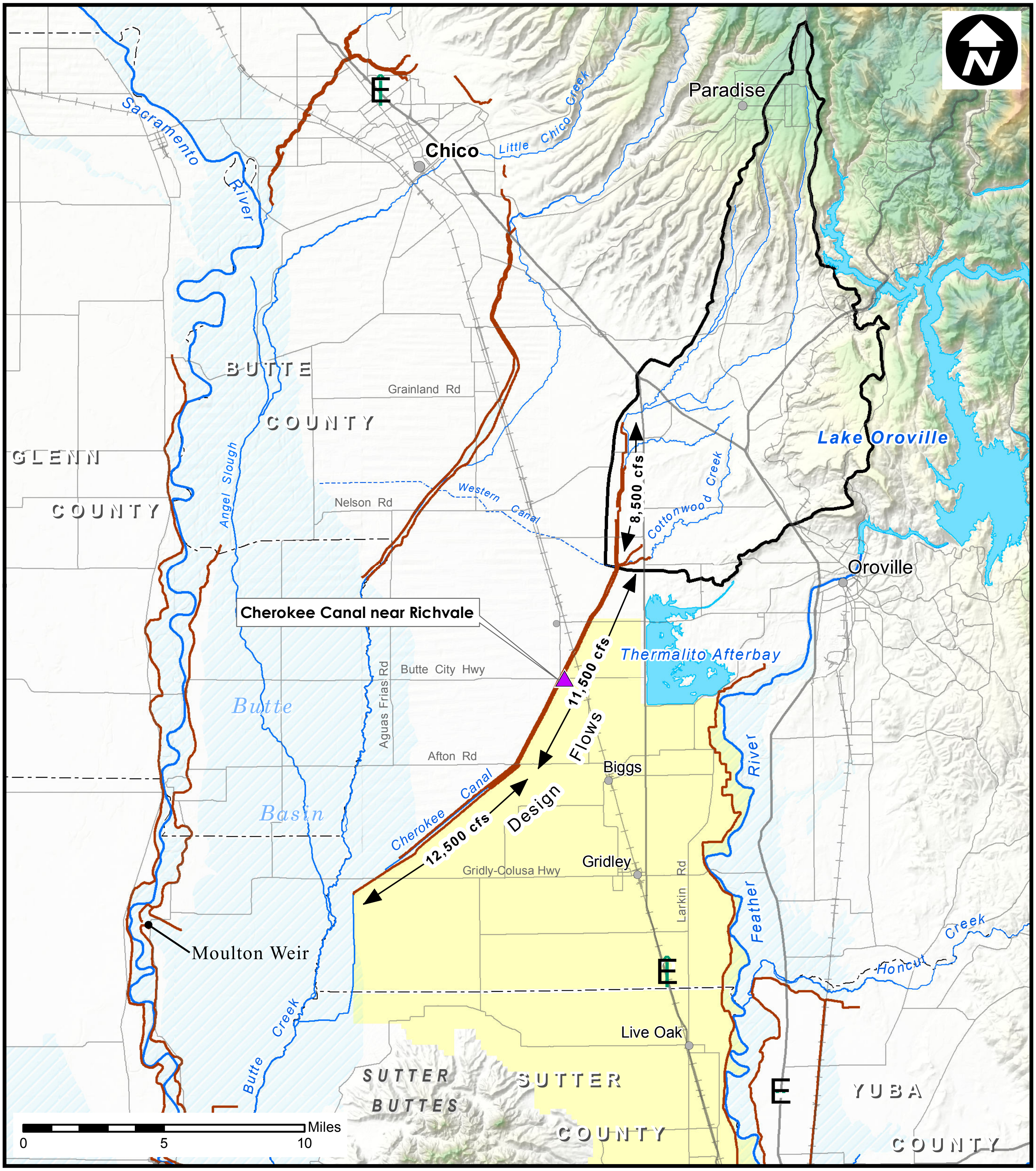
SACRAMENTO DISTRICT

NOTES:

1. WY 1977, 1972, 1990 are low outliers.
2. Median plotting positions
3. Drainage area about 94 sq. mi.
4. 46 years of record
5. DWR Station A02984

DEC 2008

PLATE 18



Legend

Stream Gage	Federal Levee
Sutter Basin Study Area	Highway
Watershed Boundary	Major Road
Designated Floodway	Railroad
Lake or Reservoir	County Boundary
River or Stream	City or Town

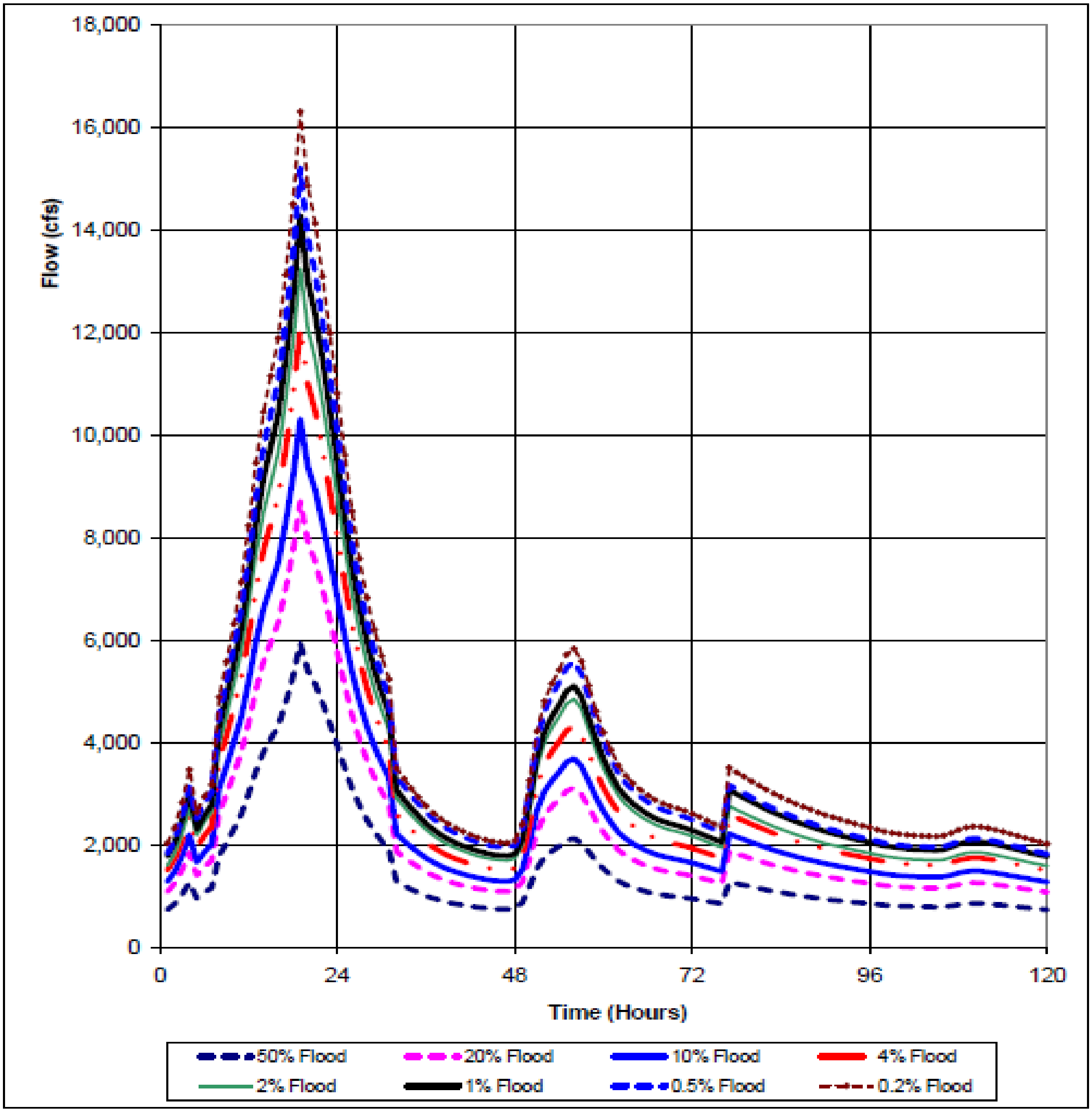
SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

CHEROKEE CANAL WATERSHED AND TOPOGRAPHY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012

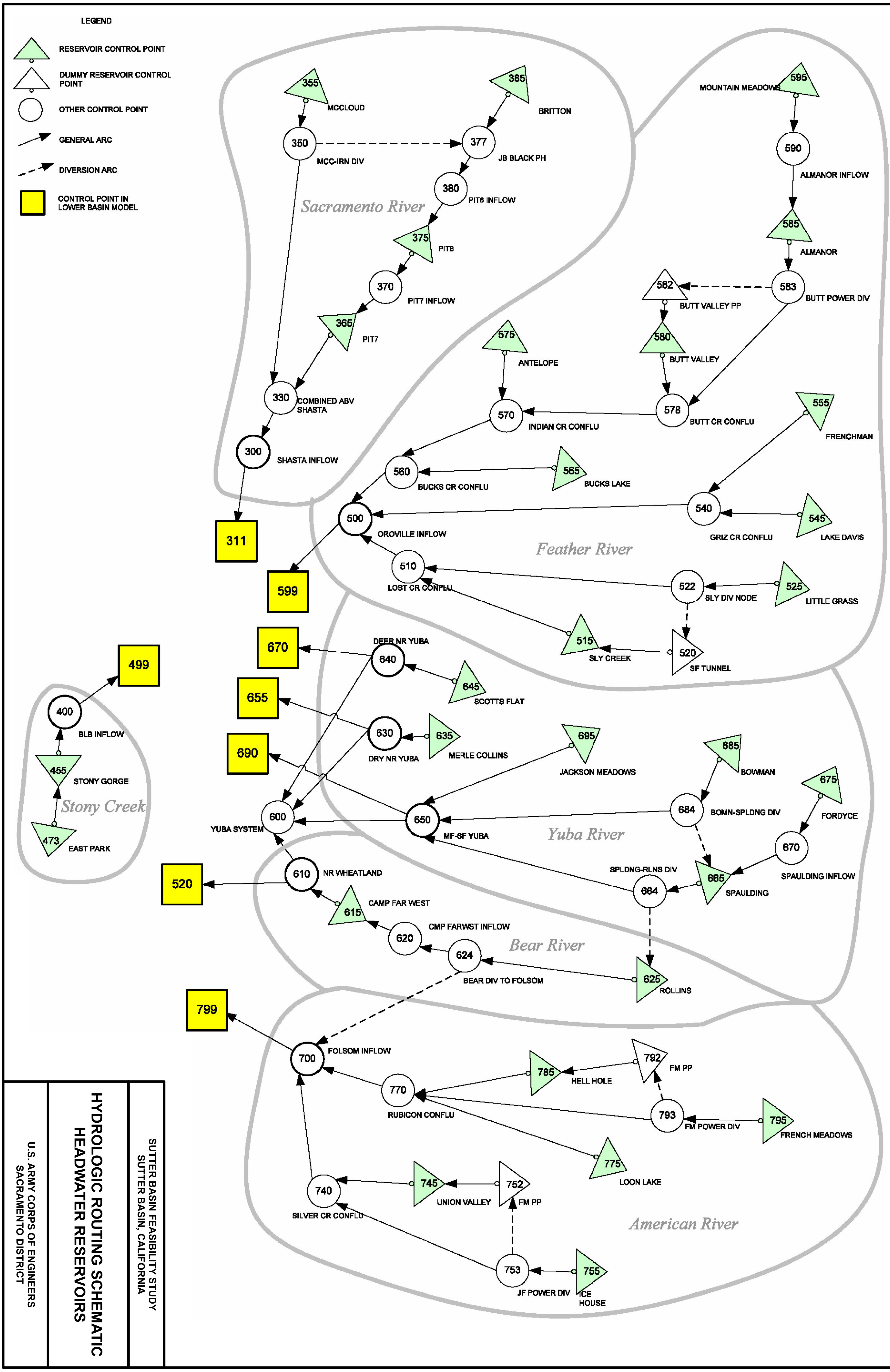


Source: Sutter County Feasibility Study, 2004

SUTTER BASIN FEASBILITY STUDY
SUTTER BASIN, CALIFORNIA

CHEROKEE CANAL
SYNTHETIC 8-FLOOD SERIES
5-DAY WAVE HYDROGRAPHS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



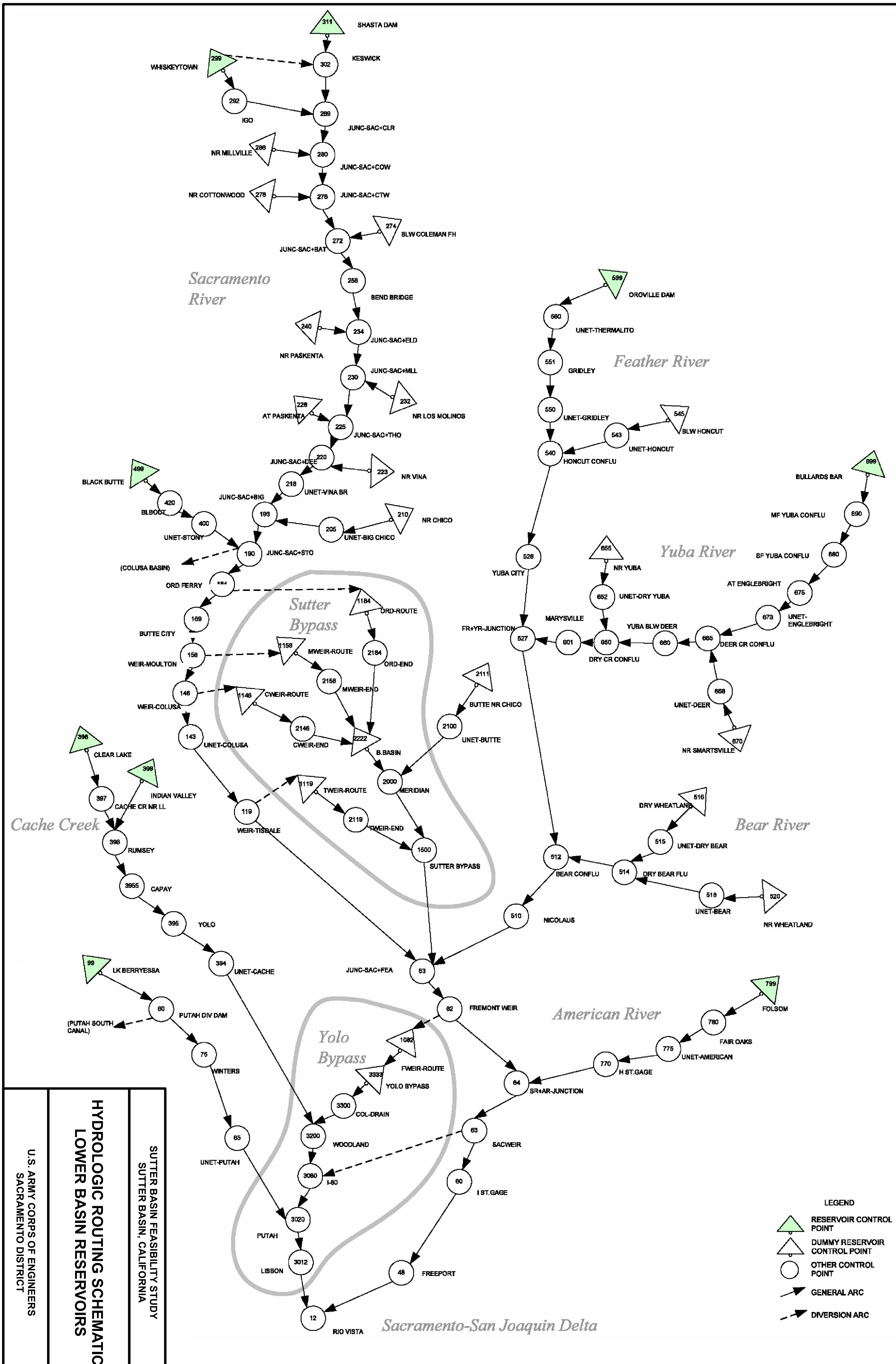
SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

HYDROLOGIC ROUTING SCHEMATIC
HEADWATER RESERVOIRS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

NOV 2012

PLATE 21



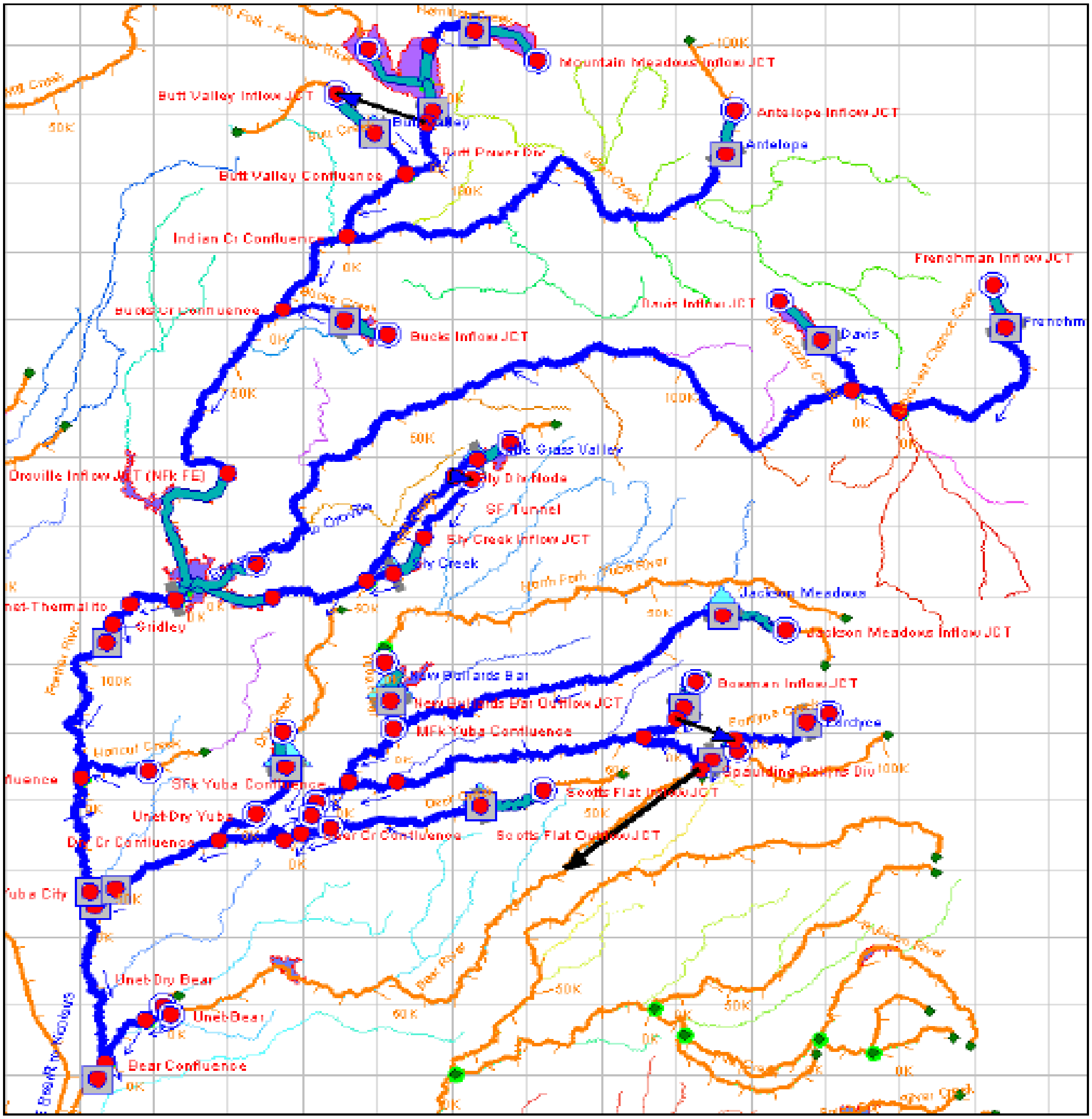
SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

HYDROLOGIC ROUTING SCHEMATIC LOWER BASIN RESERVOIRS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

NOV 2012

PLATE 22

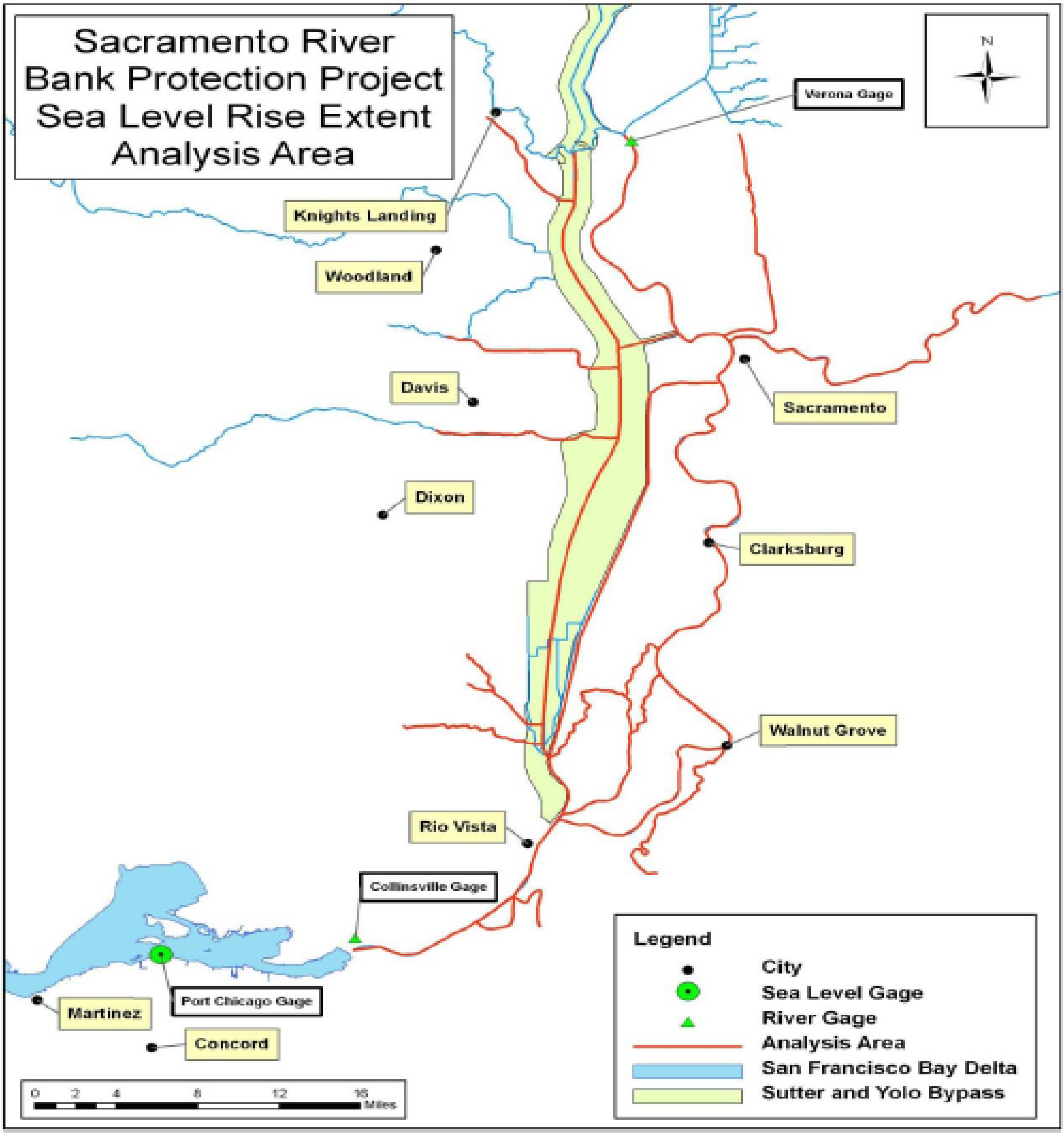


Source: Lower Feather River FPMS, 2004

SUTTER BASIN FEASBILITY STUDY
SUTTER BASIN, CALIFORNIA

ResSim Model Schematic

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



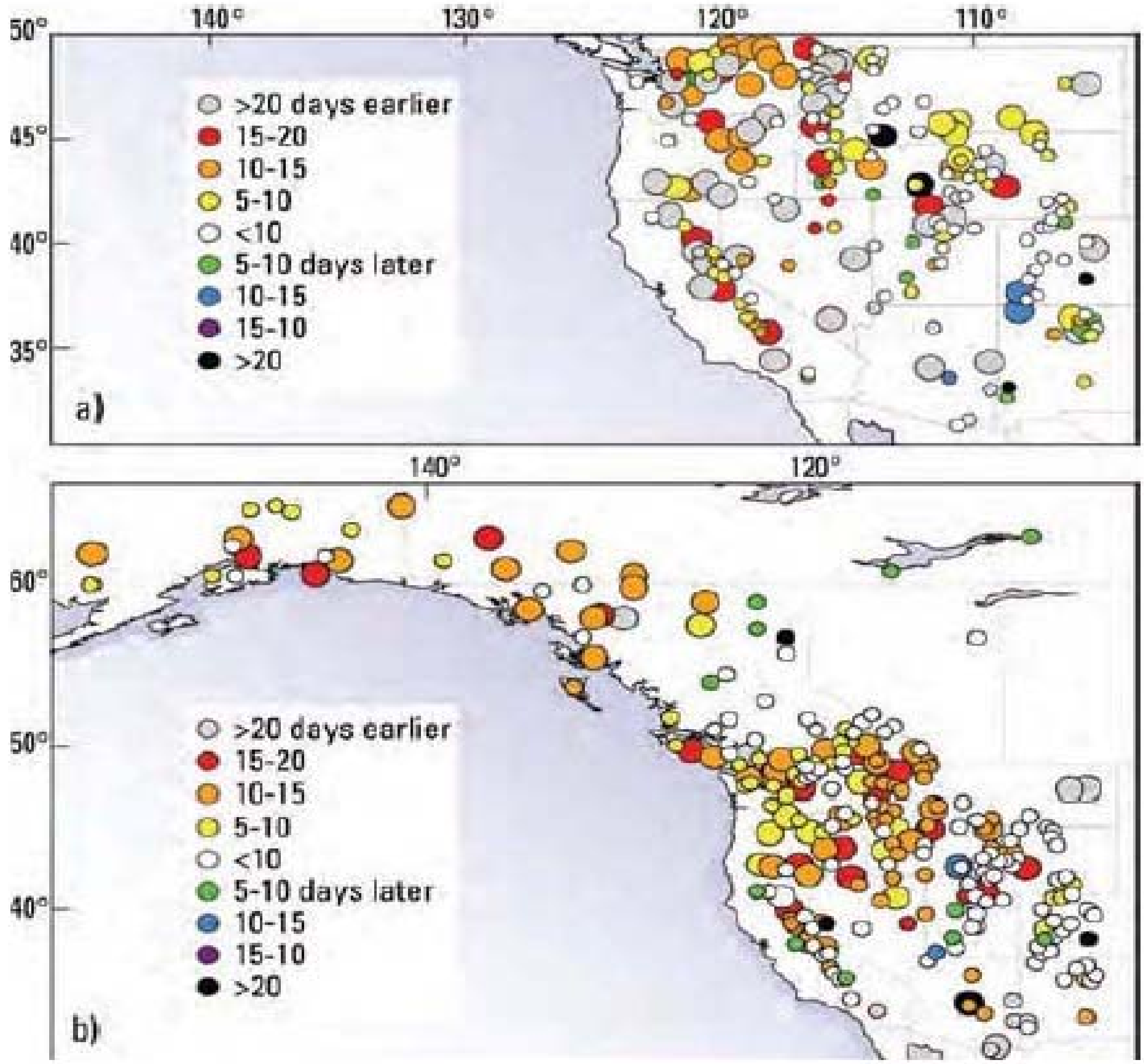
SUTTER BASIN FEASBILITY STUDY
SUTTER BASIN, CALIFORNIA

Sea Level Rise Extent
Analysis Area

Source: Sacramento Bank Protection Project, 2011

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

PLATE 24



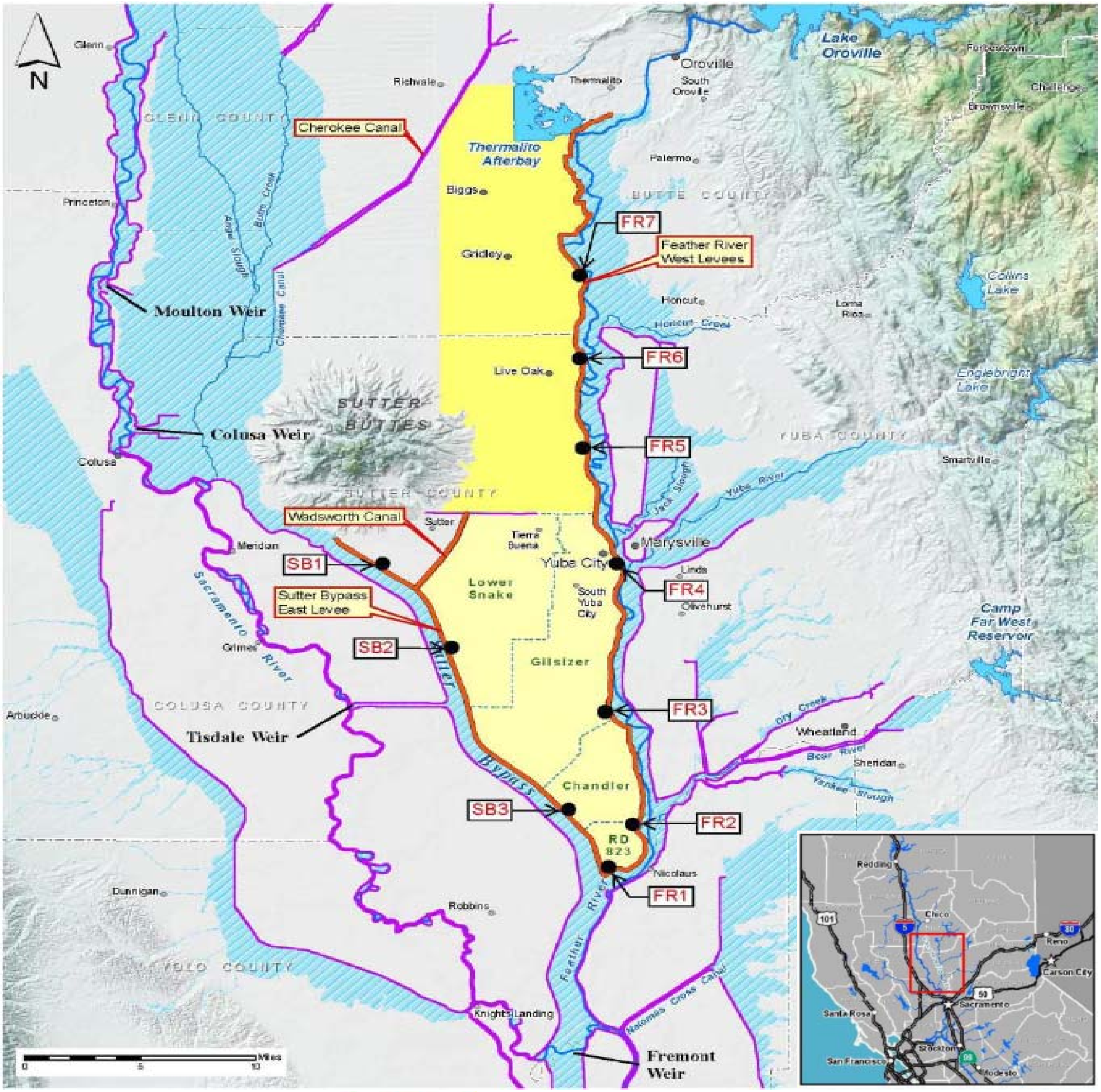
Trends in (a) yearly dates of spring snowmelt onset and (b) centers of volume of yearly streamflow hydrographs in rivers throughout western North America, based on U.S. Geological Survey streamgages in the United States and an equivalent Canadian streamflow network. Large circles indicate sites with trends that differ significantly from zero at a 90-percent confidence level; small circles are not confidently identified.

Source: USBR, Managing Water in the West, 2011.

SUTTER BASIN FEASBILITY STUDY
SUTTER BASIN, CALIFORNIA

Climate Change Trends

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Map Legend

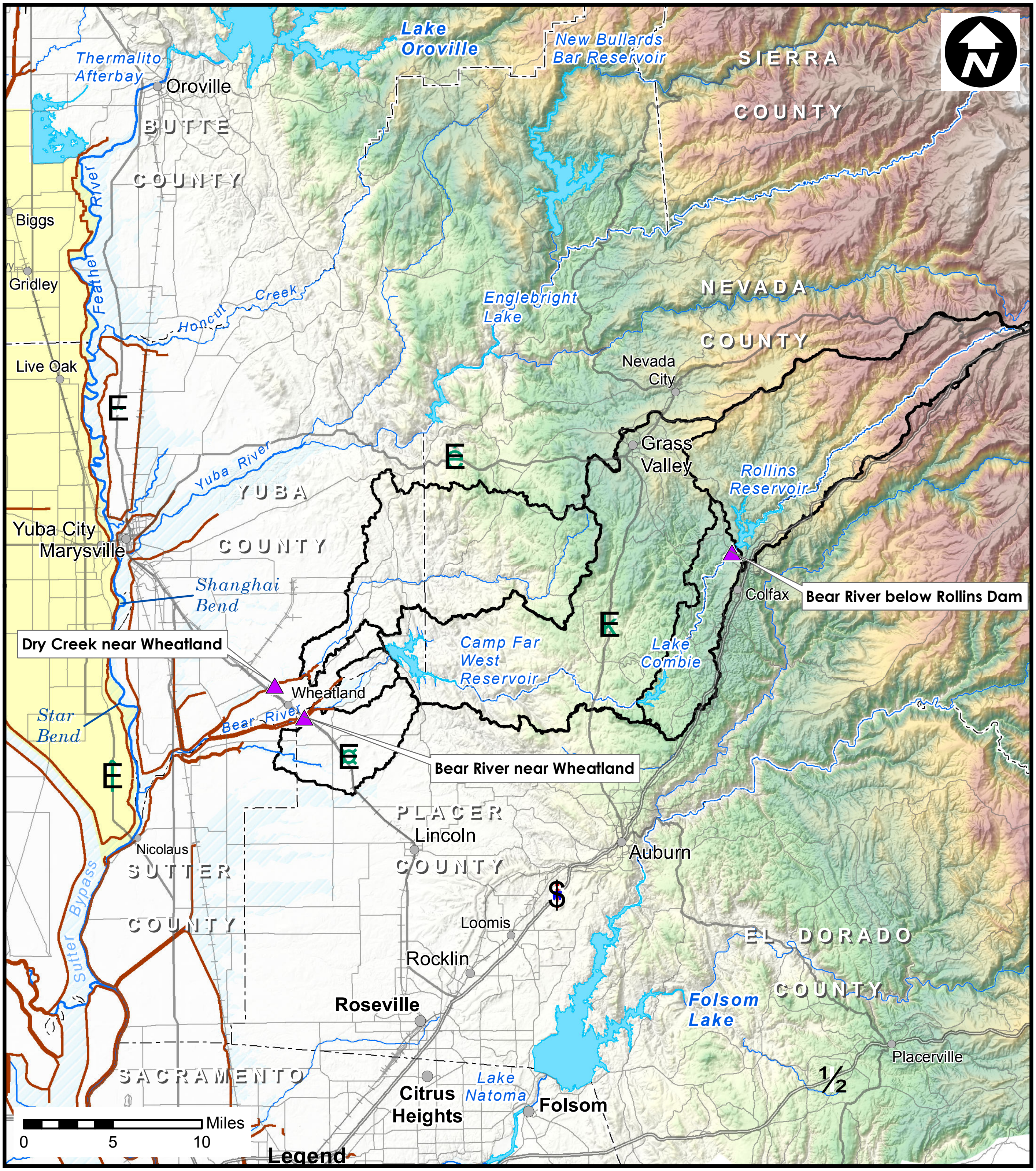
Study Area	River or Stream
Interior Drainage Area	Lake or Reservoir
Selected Levees	Designated Floodways
Federal Levee	County Boundary
Runup Sites	City or Town

Source: Ford, Wave Runup Analysis, 2011.

SUTTER BASIN FEASBILITY STUDY
SUTTER BASIN, CALIFORNIA

WAVE RUNUP STUDY AREA
WITH INTERIOR DRAINAGE AREAS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



USGS Stream Gages - CA

- USGS Stream Gages - CA
- Sutter Basin Study Area
- Watershed Boundary
- Designated Floodway
- Lake or Reservoir
- River or Stream
- Federal Levee
- Highway
- Major Road
- Railroad
- County Boundary
- City or Town

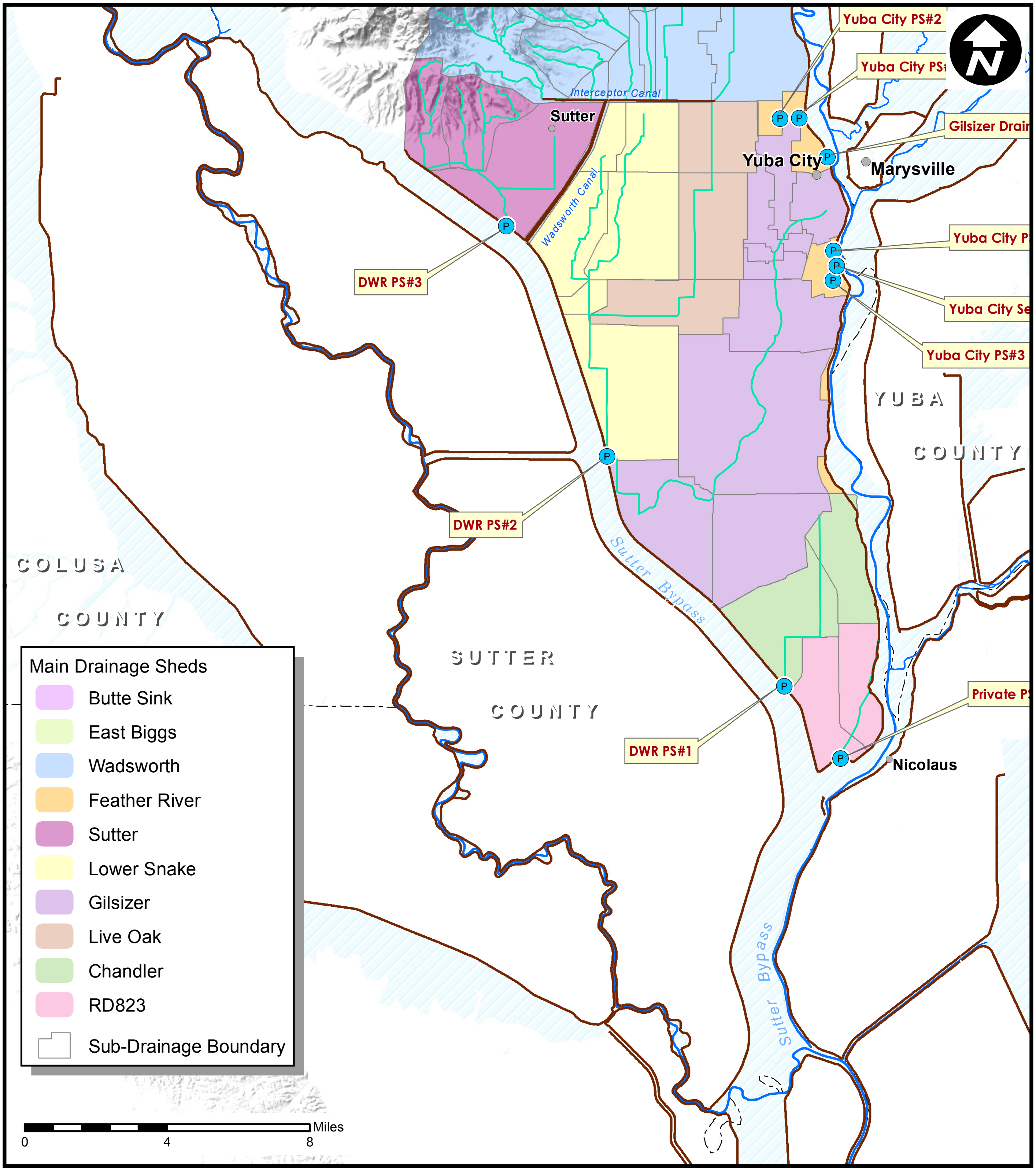
SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

BEAR RIVER WATERSHED AND TOPOGRAPHY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012



Legend

Pump Station	City or Town
Drainage Flowline	County Boundary
River or Stream	Federal Levee
Lake or Reservoir	Designated Floodway

SUTTER BASIN FEASIBILITY STUDY
SUTTER BASIN, CALIFORNIA

HEC-HMS SUBBASINS and PUMP STATIONS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by Jim Mars

NOV 2012